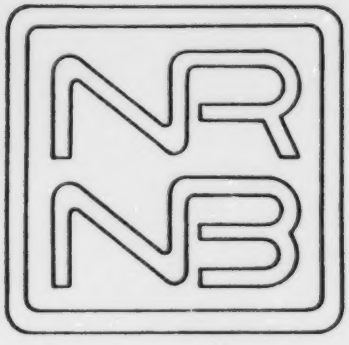
DEMONSTRATION OF AN INTEGRATED OIL SHALE RETORT SYSTEM (INTERIM REPORT NO. 1)



Mineral Resources Division
Department of Natural Resources
New Brunswick

Copies available by contacting:

Mineral Resources Division
Department of Natural Resources
P. O. Box 6000, Fredericton, N.B.
E3B 5H1

Report No.: Open File Report 85-1

Authors: S. Barua, O. Sy, P.F. Salib, D. Abbott (N.B. Research & Productivity Council, Fuel Technology Section)

Cover: Tim Fevens

Catalogue No.: ISSN 0712-4562

DEMONSTRATION OF AN INTEGRATED OIL SHALE RETORT SYSTEM

Interim Report No. 1

by

S. Barua
Process Engineer

O. Sy
Chemical Engineer

P.F. Salib
Head, Fuel Technology

D. Abbott
Head, Applied Sciences

DSS File Number 15SQ.23440-3-9086
DSS Contract Serial No.: OSQ83-00127
CANMET Scientific Authority: Dr. E. Furimsky
Period: Oct. 1 - July 20/84

Report No. AS/85/20
Date: July 31, 1984

ORIGINAL REPORT NO. 85-1

TABLE OF CONTENTS

	Page
LIST OF FIGURES AND TABLES	ii
1.0 INTRODUCTION	1
2.0 EXPERIMENTAL SET-UP OF THE OIL SHALE RETORT SYSTEM	2
3.0 RESULTS	4
3.1 Chemical Analysis of Oil Shale	4
3.2 Retorting	5
4.0 REPORT AUTHORIZATION FORM	16
5.0 APPENDIX	17

LIST OF FIGURES AND TABLES

		Page
Figure 1:	Schematic of the R.P.C. Pilot Scale Oil Shale Retort System	3
Figures 2 -32:	Operating Conditions and Temperature Profile for the Different Runs	18-79
Table 1:	Chemical Analyses of Oil Shales	4
Table 2:	Oil Shale Size Analysis	5
Table 3:	Grouping of the Successful Runs	6
Tables 4 - 7:	Summary of Experimental Conditions and Results - Sets 1 - 4	8-11
Tables 8 -11:	Properties of Shale Oil - Sets 1 - 4	12-15

1.0 INTRODUCTION

This interim report contains the experimental and analysis results obtained from the retorting of New Brunswick oil shales in both direct and indirect retorting modes. The shales were obtained from the Albert County formation from two test trenches approximately 300 m apart.

The two modes of retorting, direct and indirect, are characterized by the way the retorting heat is supplied. In direct mode, the process heat is generated inside the retort by the combustion of residual carbon. Air at room temperature is mixed with cold recycle retort gas and distributed at different bed heights for combustion. In indirect retorting mode, process heat is supplied by an outside source which, in the present experimental set-up, is an electrically heated furnace. The cold recycle retort gas was heated to a high temperature (more than 700^{o}C) and was injected inside the retort at different bed heights to ensure a good distribution of retorting heat.

The raw retorting results were compiled and from these data, different process parameters were calculated using a computer program specially developed for this purpose. The average retort temperature profile was reproduced using the CAD/CAM Facility available at RPC. The computer and CAD/CAM outputs for each run are given in the appendix.

Integration of the fluidized bed combustor with the retort is completed. The experimental program is currently underway and the results will be given in the draft final report.

2.0 EXPERIMENTAL SET-UP OF THE OIL SHALE RETORT SYSTEM

A schematic of the pilot scale retort system is shown in Figure 1. The retort has a square cross sectional area of 0.53 m^2 (0.23 m x 0.23 m) and a height of 2.4 m. Oil shale ($-\frac{1}{2}$" + 1/8") is fed into the retort by gravity through a rotary valve. As the shale descends through the retort, it is gradually heated to the retorting temperature by hot gas travelling upwards. Kerogen is released and decomposes into oil/gas products which are then swept by the retorting gas. Spent shale is discharged through an extraction screw. Off-gas containing oil undergoes several stages of separation for oil recovery: hot cyclone, condenser, packed column, electrostatic precipitator, and packed bed. Stripped gas was recycled back to the retort as bottom and middle recycles. The bottom recycle was for recovering heat from the hot spent shale. The middle recycle was injected at two levels through gas distributor pipes. The preheater was only used in the indirect mode experiments to supply necessary heat required for retorting. In the direct mode experiments, air was injected into the recycle gas stream for substaining a combustion zone in the retort. Gas sample was continuously withdrawn from the recycle stream and analyzed by on-line gas analyzers. The shale bed temperature profile was monitored by thermocouples imbedded at different levels in the retort.

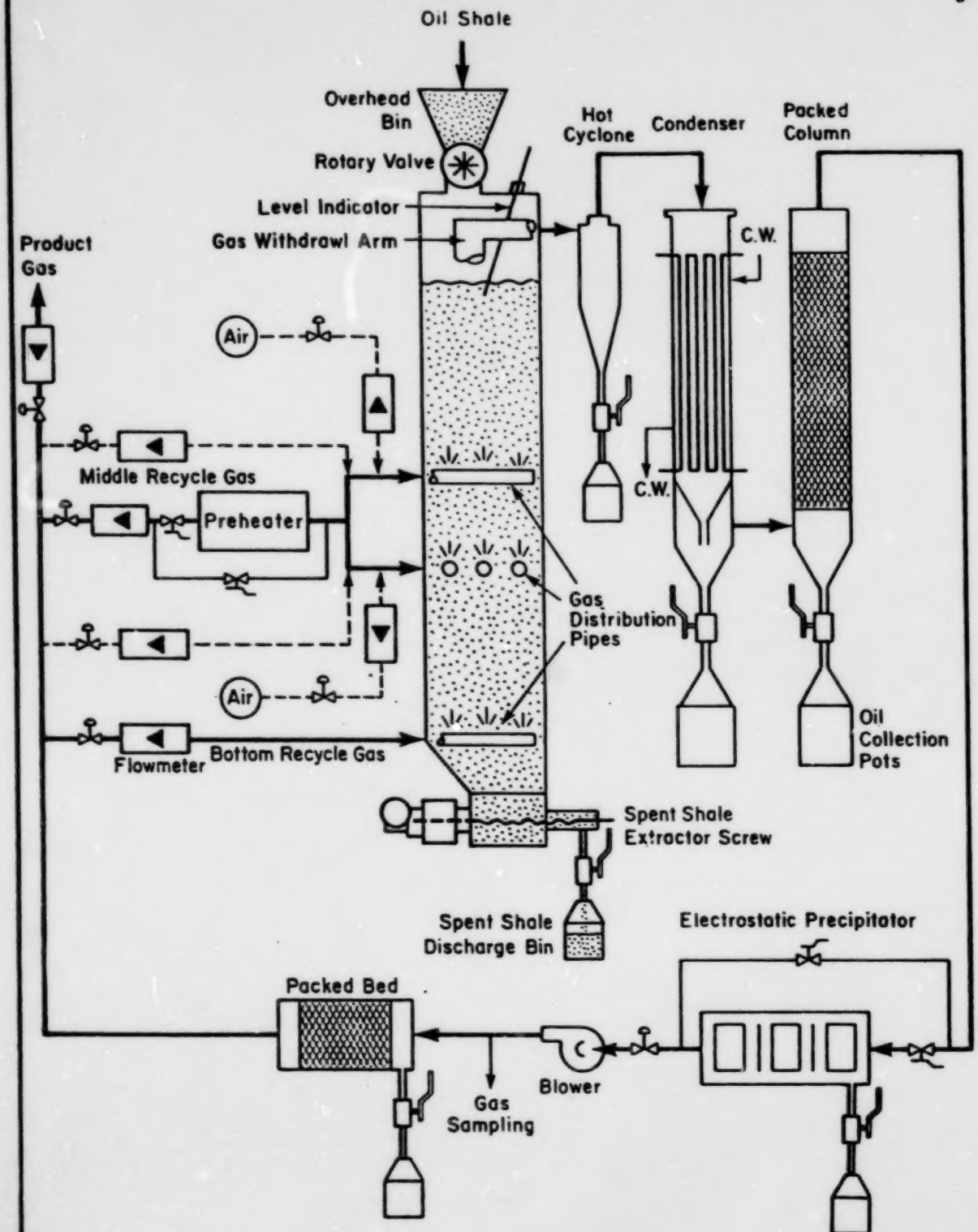


FIG. 1 : SCHEMATIC OF THE R.P.C. PILOT SCALE OIL SHALE RETORT SYSTEM

3.0 RESULTS

3.1 Chemical Analysis of Oil Shale

Oil shales from two different locations have been used in the direct and indirect retorting mode experiments. Detailed chemical analyses and Fischer assay of both shales are shown in Table 1. It can be seen that there are considerable differences in chemical compositions and Fischer assay yields between these two shales. Shale 1 can be regarded as a better quality shale than shale 2 based on these analyses.

TABLE 1
Chemical Analyses of Oil Shales

	Shale 1	Shale 2
Proximate Analysis (wt%)		
Moisture	0.68	0.43
Ash	77.55	83.16
Volatile matter	21.77	16.41
Ultimate Analysis (wt%)		
Carbon - Organic	11.40	9.95
Inorganic	3.36	1.98
Hydrogen	1.86	1.48
Nitrogen	0.10	0.30
Oxygen	4.96	2.50
Sulphur	0.77	0.63
Ash	77.55	83.16
Ash Analysis (wt%)		
SiO_2	57.82	63.71
Al_2O_3	15.62	17.14
Fe_2O_3	7.86	4.45
CaO	10.18	5.70
MgO	4.09	2.94
Na_2O	2.11	3.88
K_2O	2.32	2.18
Fischer Assay (wt%)		
Oil yield	7.76	5.91
H_2O yield	1.80	1.70
Gas lost	1.14	2.39
Oil yield (Imp Gal/ton)	21.0	15.5
Density (g/cc at 15.5°C)	0.7391	0.7592
Gross Heat of Combustion (Btu/lb)	2005	1700

Size analyses of both shales are summarized in Table 2. About 86% of the shales falls within the size range of 4 to 12.7 mm. Average particle sizes are 7.38 mm and 7.25 mm for Shale 1 and Shale 2 respectively.

TABLE 2
Oil Shale Size Analysis

Screen Size, mm (inch)	Shale 1 wt (%)	Shale 2 wt (%)
-12.7 + 9.52 (- 0.500 + 0.375)	28.74	26.84
- 9.52+ 8.0 (- 0.375 + 0.312)	13.68	11.48
- 8.0 + 4.0 (- 0.312 + 0.157)	44.00	47.74
- 4.0 + 3.36 (- 0.157 + 0.132)	4.28	5.46
- 3.36+ 2.83 (- 0.132 + 0.111)	3.65	4.99
- 2.83 fines (- 0.111 fines)	5.65	3.49

3.2 Retorting

Forty nine runs in total were attempted, excluding the short duration runs. Of the forty nine runs, thirty one were considered as successful and evaluated accordingly. First ten runs can be regarded as trial runs; however, all essential information is available on records. These will be evaluated at a later date if time permits. The other missing runs, e.g. run No. 25, 26, etc., which were not regarded as successful runs, were aborted prematurely because of their lower than expected oil yields. The short duration runs, although not recorded as other aborted runs, were made in order to explore and improve the yield. The successful runs were thus the results of these short duration runs.

First ten trial runs were in general marked by a low recovery of about 40% under comparable experimental conditions as successful runs, except for the bed height. It was found during these runs that the bed height has a significant effect on the yield. For all these trial runs, bed height was about 2.4 m as measured from the bottom of the retort. However, when it was dropped below 1.75 m, the yield improved significantly. As a result, all the runs after No. 10 were made with bed height less than 1.75 m.

All the successful runs are grouped into four sets as shown in Table 3.

TABLE 3
Grouping of the Successful Runs

	Shale No.	Retorting Mode
Set 1	1	Indirect
Set 2	2	Indirect
Set 3	1	Direct
Set 4	2	Direct

A summary of the experimental conditions and results for each set is shown in Tables 4 to 7. The properties of the oil produced are presented in Tables 8 to 11. Retort temperature profile, detailed experimental conditions and results for each experiment are shown in the appendix.

For indirect retorting, feed rates of 16, 20 and 25 kg/hr have been investigated. The experimental results given in Tables 3 and 4, indicate that the highest oil recoveries were obtained at a shale feed rate of 20 kg/hr. Therefore, all but one run in

subsequent direct retorting mode experiments (sets 3 and 4) were carried out at a shale feed rate of 20 kg/hr.

As shown in Tables 3 to 6, a wide range of experimental conditions have been investigated. The effect of the different independent process variables is currently being examined and will be included in the final report.

TABLE 4

Set 1

Summary of Experimental Conditions and Results
Mode: Indirect, Shale: 1, Fischer Assay: 21.0 Gal/ton

Run No.	Feed Rate Kg/hr	Average Bed Height m	Shale Residence Time hr	Total Recycle Gas Kg/100 kg of shale	Recycle Gas Split, kg/100 kg of shale		Retorting Recovery % of Fischer Assay	Energy Distribution % of Fresh Shale	
					Middle	Bottom		Oil	Gas
11	20	1.64	4.34	164	153.8	10.6	72.6	61.74	5.41
13	20	1.53	4.05	187	116.1	71.3	88.6	67.8	6.31
15	20	1.48	3.91	182	90.5	91.4	69.03	54.1	5.26
22	20	1.43	3.78	201	124.8	76.4	74.9	62.1	5.71
16	16	1.36	4.50	173	103.1	69.8	63.3	49.4	5.98
17	16	1.43	4.73	214	137.9	76.1	72.8	62.2	6.22
21	16	1.48	4.89	286	176.8	109.4	78.5	68.1	6.02
12	25	1.63	3.45	133	16.5	16.5	65.2	57.3	5.86
14	25	1.49	3.15	147	92.2	55.2	65.3	56.0	4.68
23	25	1.49	3.15	178	112.7	65.2	67.5	54.8	4.62

TABLE 5

Set 2

Summary of Experimental Conditions and Results
Mode: Indirect, Shale: 2, Fischer Assay: 15.5 Gal/Ton

Run No.	Feed Rate Kg/hr	Average Bed Height m	Shale Residence Time hr	Total Recycle Gas kg/100 kg of shale	Recycle Gas Split, Kg/100 kg of shale		Retorting Recovery % of Fischer Assay	Energy Distribution % of Fresh Shale	
					Middle	Bottom		Oil	Gas
27	20	1.41	3.73	211	132.4	78.6	89.3	68.7	7.33
28	20	1.53	4.05	197	120.7	76.1	70.2	56.4	6.52
29	20	1.60	4.22	243	151.3	91.5	93.2	68.5	5.77
35	20	1.62	4.28	247	161.0	86.2	84.3	70.2	4.31
32	16	1.62	5.36	257	161.0	95.7	72.5	53.5	5.43
34	16	1.57	5.19	293	185.0	107.6	67.7	50.3	6.4
30	25	1.61	3.41	215	157.0	58.4	78.5	58.0	4.55
31	25	1.58	3.34	224	153.7	70.0	72.7	54.0	3.82

TABLE 6

Set 3

Summary of Experimental Conditions and Results
Mode: Direct, Shale: 1, Fischer Assay: 21.0 Gal/ton

Run No.	Feed Rate kg/hr	Average Bed Height m	Shale Residence Time hr	Total Air kg/100 kg of shale	Air Split wt% Middle	Air Split wt% Bottom	Total Recycle Gas kg/100 kg of shale	Recycle Gas Split, wt% Middle	Recycle Gas Split, wt% Bottom	Retorting Recovery % Fischer Assay	Energy Distribution % Fresh Shale Oil	Energy Distribution % Fresh Shale Gas
18	20	1.43	3.78	31.4	100	0.0	117	55	45	60.4	49.64	11.0
20	25	1.51	3.20	28.74	100	0.0	144	12	88	75.1	63.4	8.7
36	20	1.55	4.10	28.44	77	23.0	153	19	81	61.6	40.20	21.4
37	20	1.52	4.02	35.7	74	26.0	148	26	74	63.6	40.2	10.5
46	20	1.74	4.60	32.84	100	0.0	170	23	77	77.3	60.1	12.3
47	20	1.55	4.10	30.89	100	0.0	213	16	84	81.4	64.4	10.3
48	20	1.46	3.86	27.62	100	0.0	212	12	88	71.4	56.3	11.8
49	20	1.61	4.26	39.32	100	0.0	218	21	79	61.8	50.1	14.5

TABLE 7

Set 4

Summary of Experimental Conditions and Results
Mode: Direct, Shale: 2, Fischer Assay: 15.5 Gal/ton

Run No.	Feed Rate kg/hr	Average Bed Height m	Shale Residence Time hr	Total Air kg/100 kg of shale	Air Split wt% Middle	Air Split wt% Bottom	Total Recycle Gas kg/100 kg of shale	Recycle Gas Split, wt% Middle	Recycle Gas Split, wt% Bottom	Retorting Recovery % Fischer Assay	Energy Distribution % Fresh Oil	Energy Distribution % Shale Gas
41	20	1.74	4.60	30.64	100	0	217	14	86	63.9	46.63	11.60
42	20	1.74	4.60	30.59	100	0	189	16	84	59.3	43.9	12.33
43	20	1.74	4.60	30.11	100	0	164	19	81	58.5	44.08	11.33
44	20	1.58	4.18	29.07	100	0	171	20	80	71.1	58.97	17.45
45	20	1.69	4.47	39.94	100	0	176	24	76	65.3	49.26	14.43

TABLE 8

Set 1

Properties of Shale Oil*
Mode: Indirect, Shale: 1, Fischer Assay: 21.0 Gal/Ton

Run No.	API Gravity	Elemental Analysis wt% C	H	N	S	H/C Ratio	Pour Point °F	Kinematic Viscosity Cst @ 122°F	Heating Value Btu/lb	% Recovery
11	30.4	86.26	12.16	0.65	0.47	1.69	70	5.73	18776	72.6
12	31.1	86.16	12.17	0.80	0.51	1.69	70	5.44	18943	65.2
13	28.7	86.51	11.95	0.79	0.47	1.66	75	8.44	18504	88.6
14	30.2	86.23	12.28	0.80	0.48	1.70	70	6.75	18549	65.3
15	29.8	86.41	12.19	0.82	0.46	1.69	75	7.47	18619	69.03
16	30.0	85.46	12.07	0.68	0.52	1.69	70	8.88	18701	63.3
17	29.5	86.09	11.92	0.96	0.52	1.66	75	8.79	18632	72.8
21	27.8	86.12	12.01	0.94	0.55	1.67	70	10.17	18512	78.5
22	27.5	86.03	11.87	0.97	0.53	1.66	75	11.37	18490	74.9
23	29.5	86.02	12.02	0.92	0.54	1.68	75	8.14	18592	67.5

* Flash points will be included in the Final Report.

TABLE 9

Set 2

Properties of Shale Oil
Mode: Indirect, Shale: 2, Fischer Assay: 15.5 Coal/ton

Run No.	API Gravity	Elemental Analysis wt% C	H	N	S	H/C Ratio	Pour Point °F	Kinematic Viscosity Cst @ 122°F	Heating value Btu/lb	% Recovery
27	21.8	86.46	11.80	1.16	0.28	1.64	60	13.40	18302	89.3
28	25.2	86.29	11.78	1.28	0.30	1.64	60	16.75	18461	70.2
29	22.6	86.38	11.62	1.37	0.29	1.61	60	17.32	17379	93.2
30	23.1	86.22	11.61	1.35	0.26	1.62	55	18.42	17541	72.7
31	23.3	86.55	11.39	1.07	0.30	1.58	55	17.59	17651	72.7
32	25.0	85.42	11.11	1.29	0.28	1.56	60	19.25	17929	72.5
34	26.2	86.26	11.38	1.35	0.26	1.58	55	11.59	18263	67.7
35	25.0	86.36	11.08	1.24	0.25	1.54	55	10.79	18384	84.3

TABLE 10

Set 3

Properties of Shale Oil
Mode: Direct, Shale: 1, Fischer Assay: 21.0 Gal/Ton

Run No.	API Gravity	Elemental Analysis wt% C	H	N	S	H/C Ratio	Pour Point °F	Kinematic Viscosity Cst @ 122°F	Heating Value Btu/lb	% Recovery
36	25.9	86.04	11.04	1.18	0.25	1.54	60	12.80	18393	61.6
37	27.1	85.51	11.3	1.04	0.25	1.59	60	10.93	18563	63.6
46	29.5	85.96	11.55	0.79	0.49	1.61	70	8.14	18569	77.3
47	28.0	86.19	11.81	0.83	0.54	1.64	75	11.61	18770	81.4
48	28.2	86.38	11.27	0.84	0.54	1.57	70	10.34	18772	71.4
49	29.3	86.51	11.62	0.80	0.48	1.61	70	8.06	18833	61.8

TABLE 11

Set 4

Properties of Shale Oil
Mode: Direct, Shale: 2, Fischer Assay: 15.5 Gal/Ton

Run No.	API Gravity	Elemental Analysis wt% C	H	N	S	H/C Ratio	Pour Point °F	Kinematic Viscosity Cst @ 122°F	Heating Value Btu/lb	% Recovery
41	27.5	86.11	11.31	1.25	0.25	1.58	60	12.82	18523	63.9
42	25.7	85.41	11.33	1.14	0.24	1.59	60	15.80	18370	59.3
43	15.9	86.61	11.04	1.23	0.23	1.53	55	12.92	18485	58.5
44	25.5	86.18	11.56	1.28	0.22	1.61	55	14.10	18536	71.1
45	25.2	86.09	11.06	1.29	0.25	1.54	60	14.23	18565	65.3

4.0

AUTHORIZATION

DEPARTMENT: APPLIED SCIENCES

PROJECT TITLE: DEMONSTRATION OF AN INTEGRATED OIL SHALE RETORT SYSTEM

PROJECT NUMBER: 50199 PROPOSAL NUMBER

REPORT AS/85/20

Prepared By: S. Barua
O. Sy
P. Salib

Reviewed By: P. Salib

Approved By: D. Abbott for P. Salib

Date: August 8, 1984

rpc RESEARCH AND PRODUCTIVITY COUNCIL
P.O. Box 6000, Fredericton, New Brunswick, Canada, E3B 5H1
Telephone (506) 452-8994
Telex 014-46115

5.0 APPENDIX

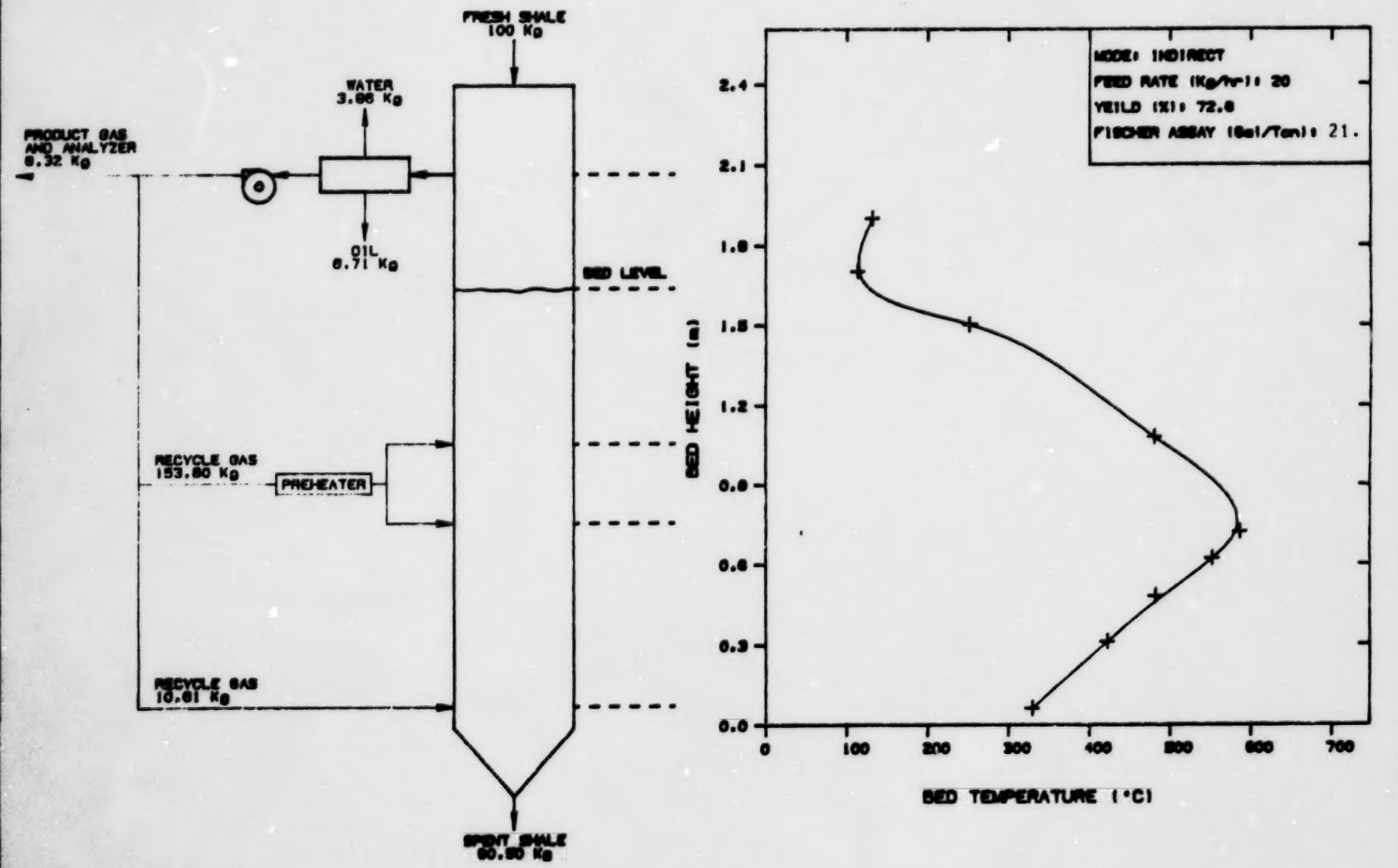


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 11

EXPERIMENT NO:11 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.64
FEED RATE, KG/HR: 20.00
DURATION, HR: 17.00
RESIDENCE TIME IN HR: 4.34
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.64
RECYCLE GAS SPLIT, %: BOTTOM: 6.5 MIDDLE: 93.5

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 1.72
TOTAL INPUT: 101.72

OUTPUT IN KG

SPENT SHALE: 90.50
EXHAUST GAS: 0.
ANALYZER INTAKE: 8.32
OIL PRODUCED: 6.71
WATER FORMED: 3.86
TOTAL OUTPUT: 109.39
% UNACCOUNTED: -7.54

BOTTOM RECYCLE GAS, KG: 10.61
MIDDLE RECYCLE GAS, KG: 153.80

GAS ANALYSIS IN MOL %

N2: 3.76
H2: 81.48
O2: 1.19
CO2: 6.07
CO: 3.85
CH4: 0.56
C2: 1.06
C3: 1.980
C4: 0.050

BTU PER SCFM: 104.60

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 3.83
% OIL 49.73
% SPENT SHALE: 36.06
% GAS: 4.99

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 61.74
GAS: 8.41

YIELD, % OF F.A: 72.60

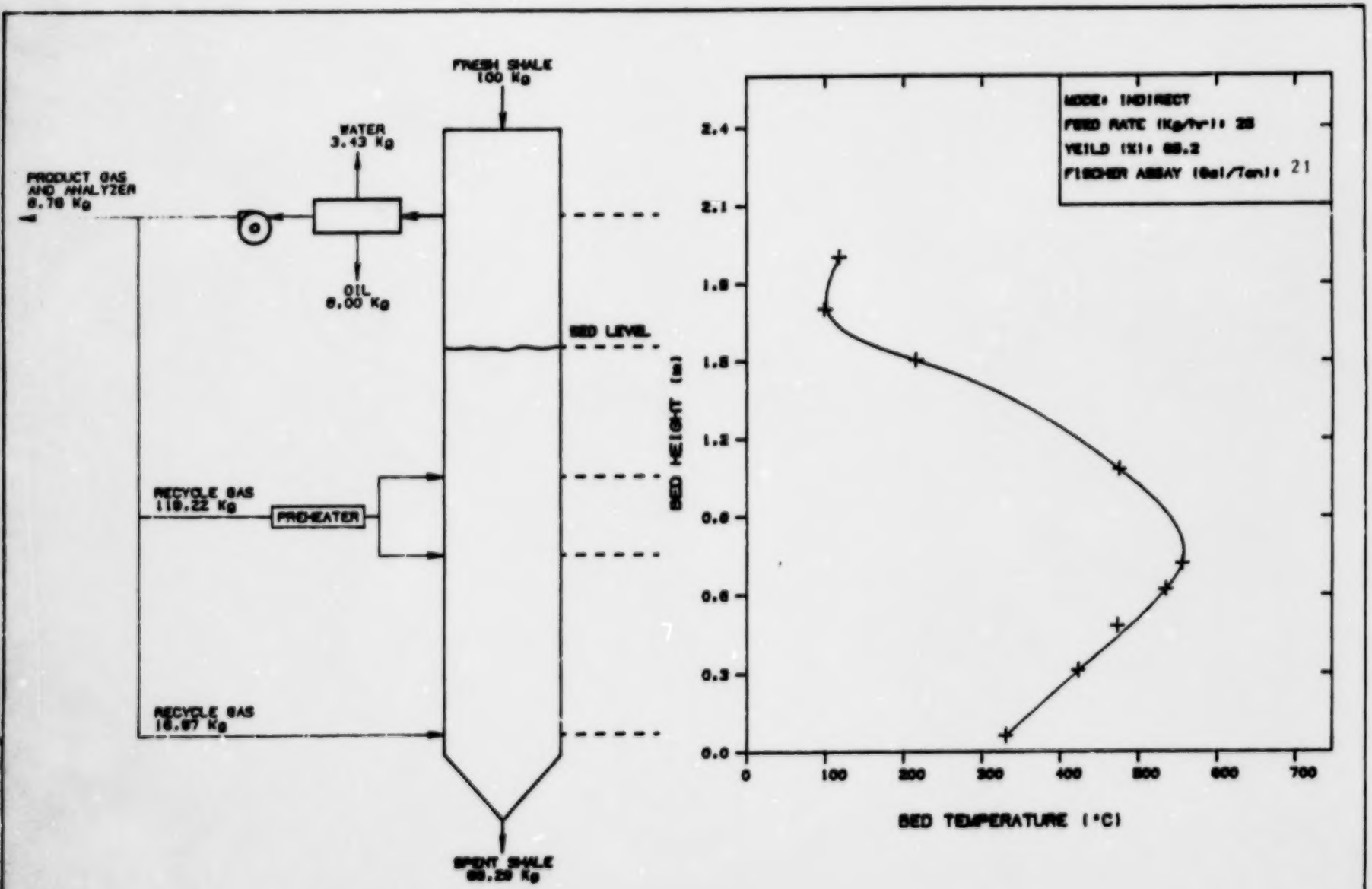


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 12

EXPERIMENT NO:12 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.63
FEED RATE, KG/HR: 25.00
DURATION, HR: 17.00
RESIDENCE TIME IN HR: 3.45
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.33
RECYCLE GAS SPLIT, %: BOTTOM: 12.4 MIDDLE: 87.6

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -1.03
TOTAL INPUT: 98.97

OUTPUT IN KG

SPENT SHALE: 88.29
EXHAUST GAS: 0.
ANALYZER INTAKE: 6.61
OIL PRODUCED: 6.00
WATER FORMED: 3.43
TOTAL OUTPUT: 104.33
% UNACCOUNTED: -5.42

BOTTOM RECYCLE GAS, KG: 16.45
MIDDLE RECYCLE GAS, KG: 116.25

GAS ANALYSIS IN MOL %

H2: 4.10
N2: 79.15
O2: 1.17
CO2: 5.46
CO: 4.69
CH4: 0.56
C2: 2.89
C3: 2.010
C4: 0.200

BTU PER SCFM: 137.75

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 4.87
% OIL 48.72
% SPENT SHALE: 40.85
% GAS: 4.84

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 57.26
GAS: 5.88

YIELD, % OF F.A: 68.20

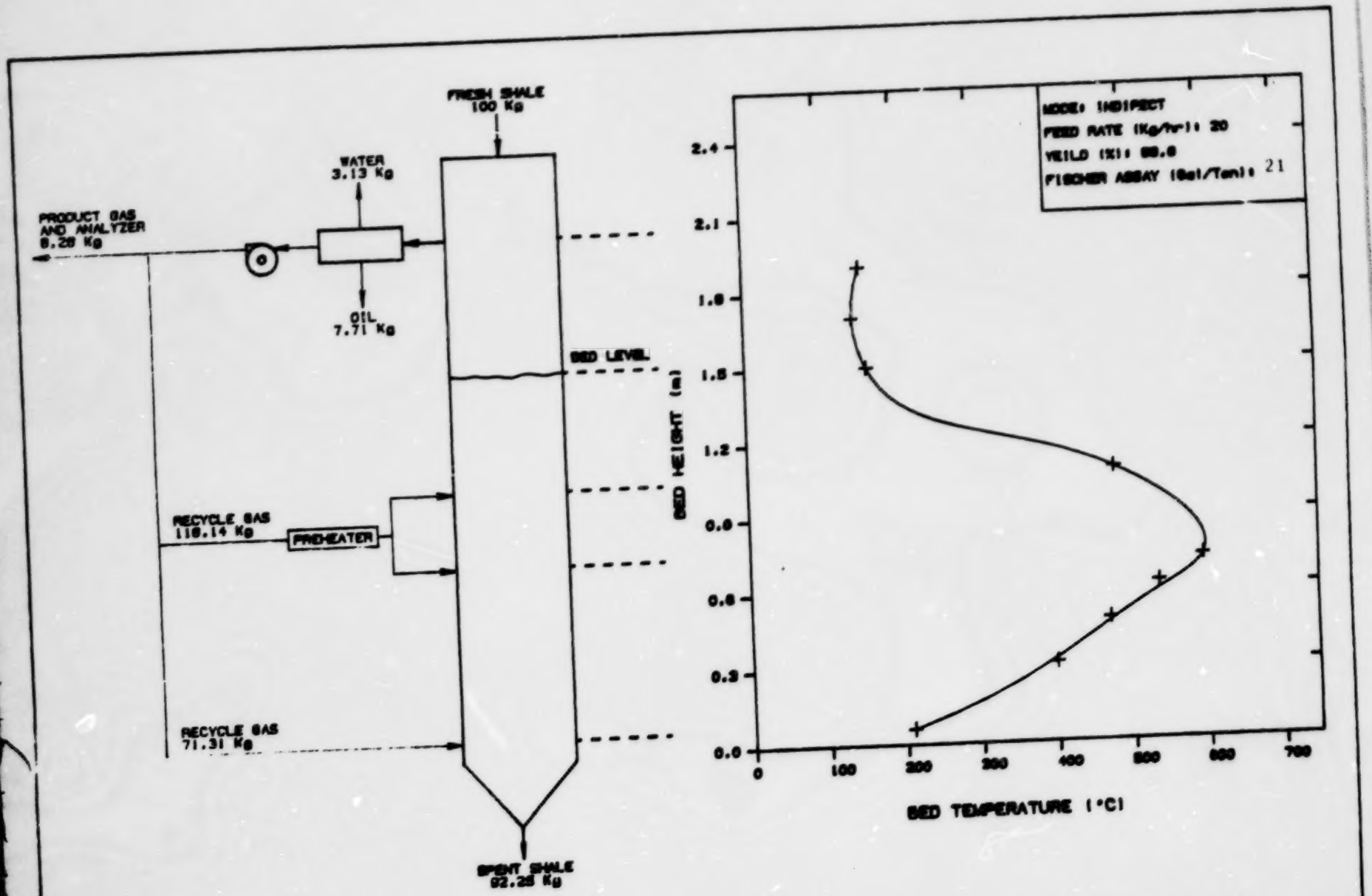


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 13

EXPERIMENT NO:13 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.53
FEED RATE, KG/HR: 20.00
DURATION, HR: 13.00
RESIDENCE TIME IN HR: 4.05
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.87
RECYCLE GAS SPLIT, %: BOTTOM: 38.0 MIDDLE: 62.0

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 5.05
TOTAL INPUT: 105.05

OUTPUT IN KG

SPENT SHALE: 92.25
EXHAUST GAS: 0.
ANALYZER INTAKE: 8.26
OIL PRODUCED: 7.71
WATER FORMED: 3.13
TOTAL OUTPUT: 111.36
% UNACCOUNTED: -6.00

BOTTOM RECYCLE GAS, KG: 71.81
MIDDLE RECYCLE GAS, KG: 116.14

GAS ANALYSIS IN MOL %

H2: 4.30
N2: 79.35
O2: 1.30
CO2: 6.00
CO: 4.16
CH4: 1.11
C2: 1.70
C3: 2.030
C4: 0.050

BTU PER SCFM: 125.81

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: -1.69
% OIL 55.38
% SPENT SHALE: 37.90
% GAS: 5.72

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 67.75
GAS: 6.81

YIELD, % OF F.A: 88.60

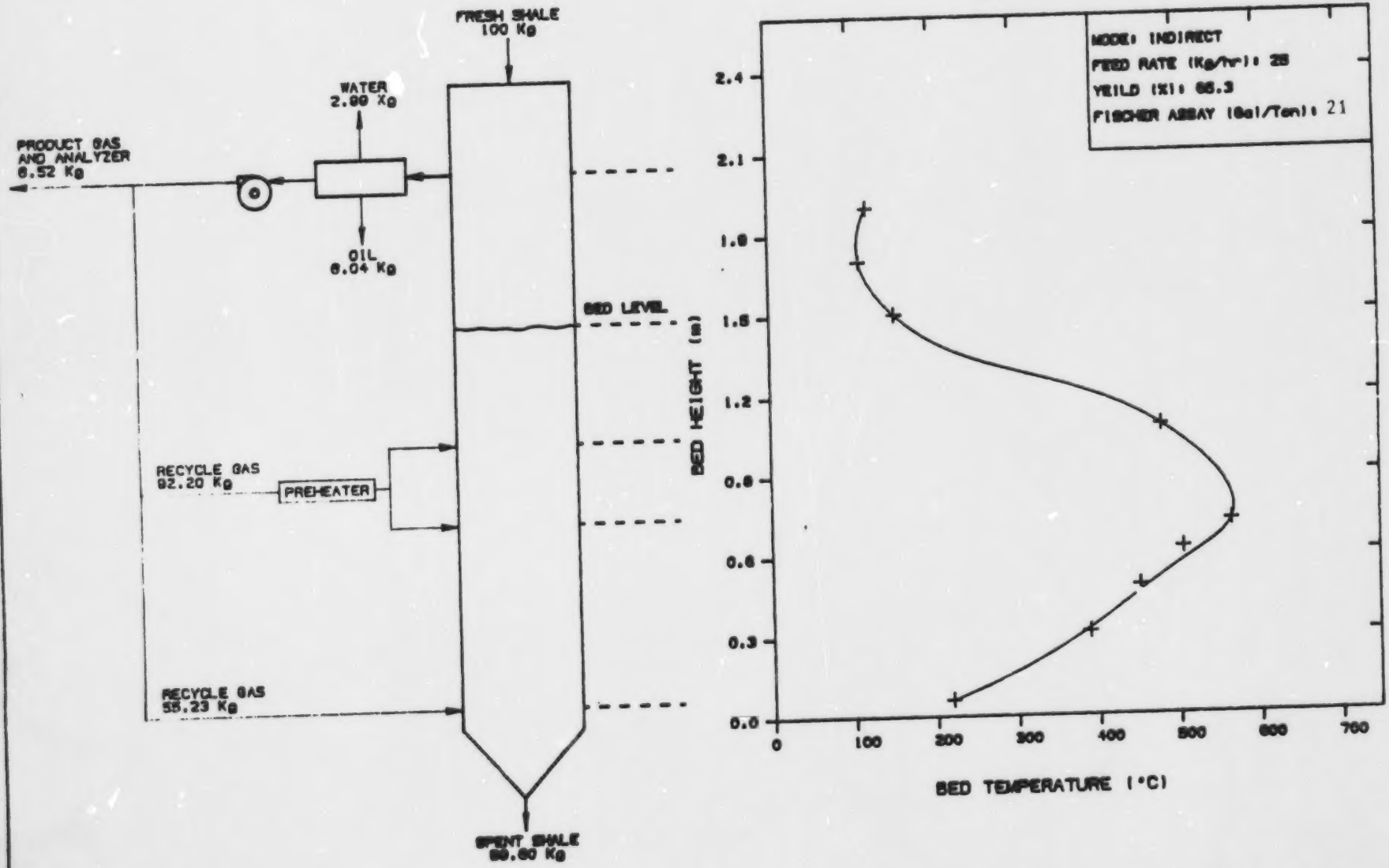


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 14

EXPERIMENT NO:14 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.49
FEED RATE, KG/HR: 25.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 3.15
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.47
RECYCLE GAS SPLIT, %: BOTTOM: 37.5 MIDDLE: 62.5

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.49
TOTAL INPUT: 100.49

OUTPUT IN KG

SPENT SHALE: 89.60
EXHAUST GAS: 0.
ANALYZER INTAKE: 6.52
OIL PRODUCED: 5.04
WATER FORMED: 2.99
TOTAL OUTPUT: 105.15
% UNACCOUNTED: -4.64

BOTTOM RECYCLE GAS, KG: 55.23
MIDDLE RECYCLE GAS, KG: 92.20

GAS ANALYSIS IN MOL %

H2: 5.19
N2: 79.92
O2: 1.20
CO2: 5.40
CO: 4.19
CH4: 0.99
C2: 1.82
C3: 1.530
C4: 0.060

BTU PER SCFM: 111.64

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 5.61
% OIL 45.34
% SPENT SHALE: 40.20
% GAS: 3.69

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 55.99
GAS: 4.68

YIELD, % OF F.A: 65.30

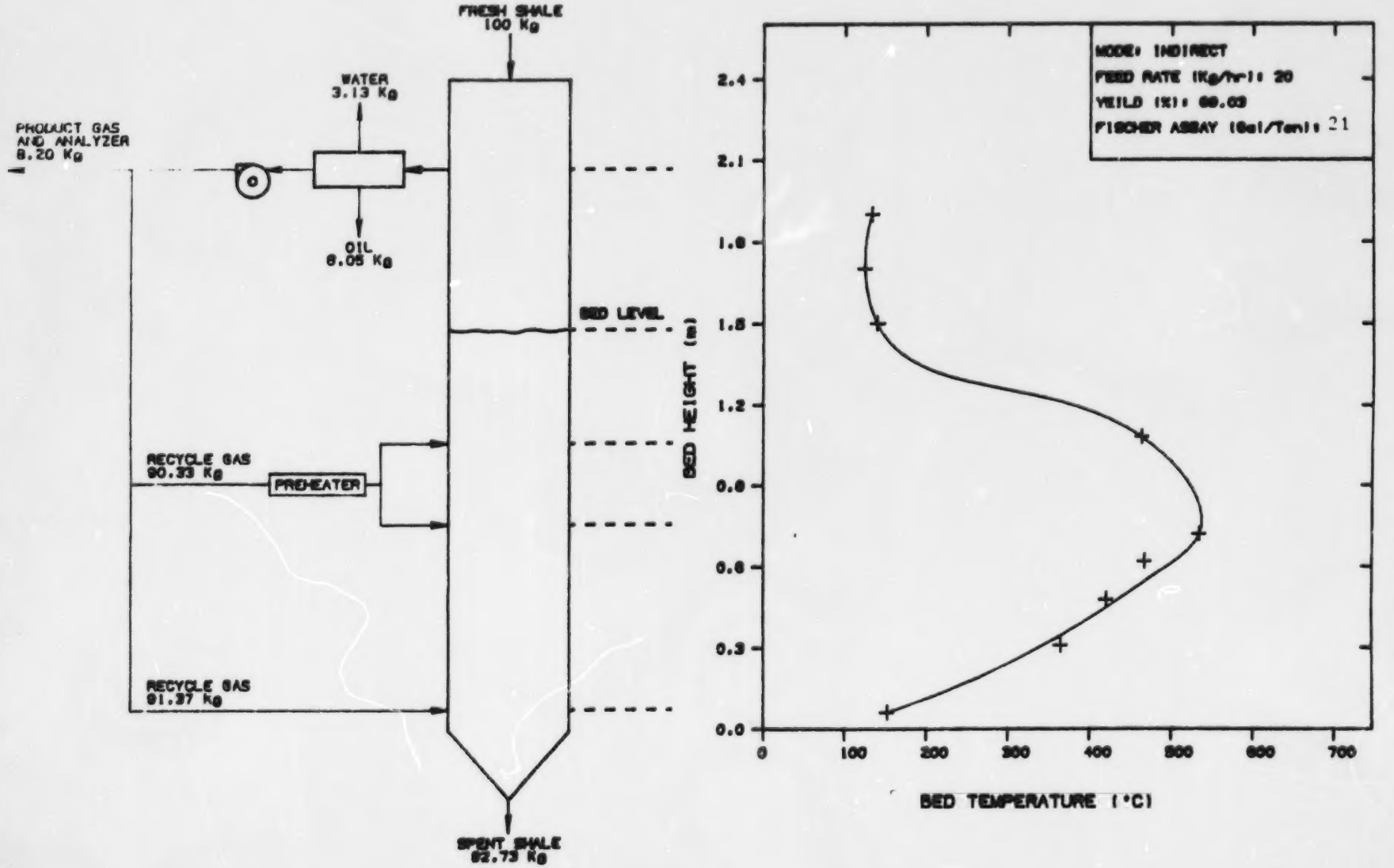


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 15

EXPERIMENT NO:16 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.48
FEED RATE, KG/HR: 20.00
DURATION, HR: 13.00
RESIDENCE TIME IN HR: 3.91
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.82
RECYCLE GAS SPLIT, %: BOTTOM: 50.3 MIDDLE: 49.7

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 3.93
TOTAL INPUT: 103.93

OUTPUT IN KG

SPENT SHALE: 92.73
EXHAUST GAS: 0.
ANALYZER INTAKE: 8.20
OIL PRODUCED: 6.05
WATER FORMED: 3.13
TOTAL OUTPUT: 110.12
% UNACCOUNTED: -5.95

BOTTOM RECYCLE GAS, KG: 91.87
MIDDLE RECYCLE GAS, KG: 90.33

GAS ANALYSIS IN MOL %

H2: 4.40
N2: 80.08
O2: 1.40
CO2: 5.60
CO: 4.60
CH4: 1.19
C2: 1.37
C3: 1.290
C4: 0.070

BTU PER SCFM: 103.82

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 2.77
% OIL 48.91
% SPENT SHALE: 41.95
% GAS: 4.76

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 54.06
GAS: 5.26

YIELD, % OF F.A: 59.03

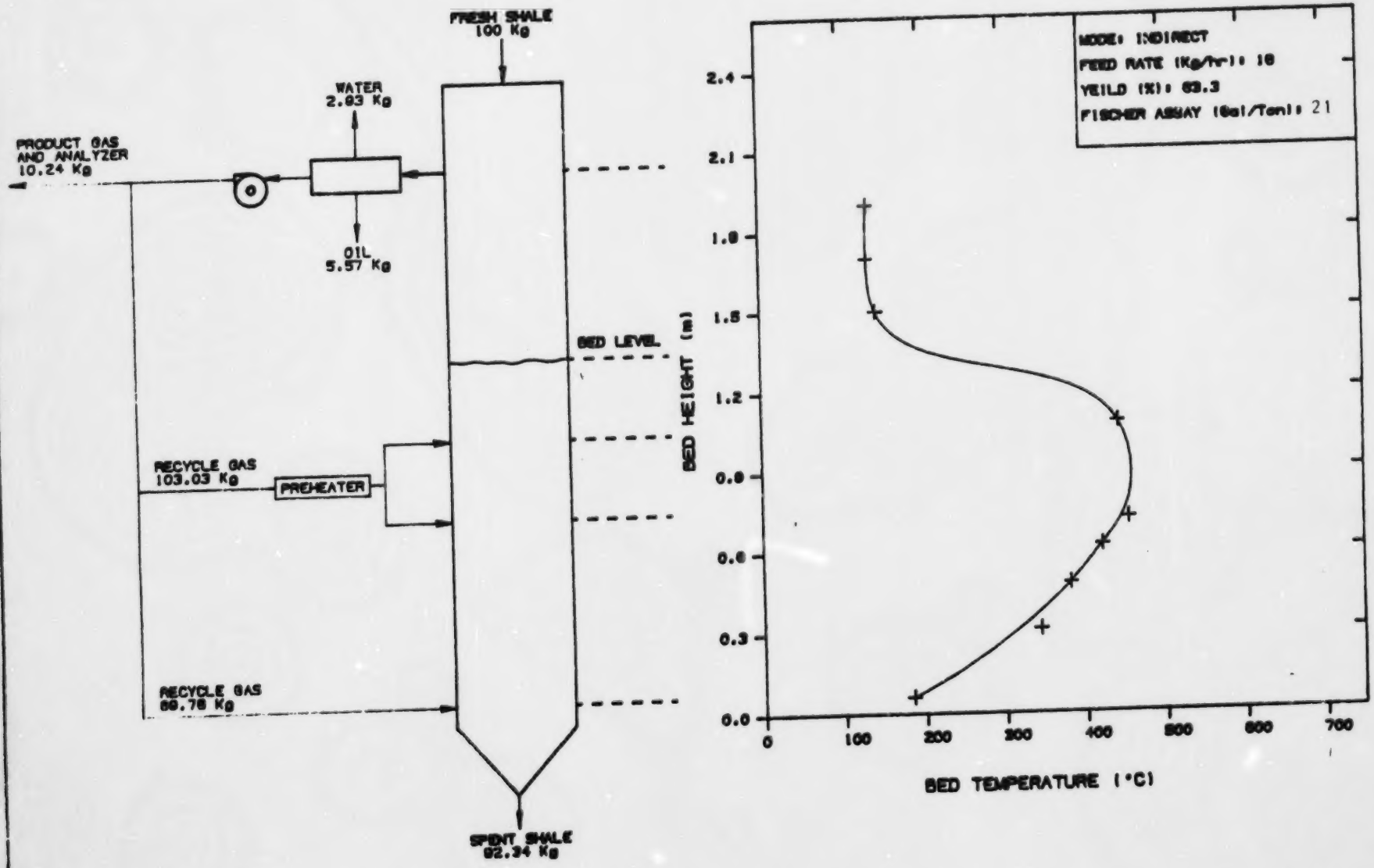


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 16

EXPERIMENT NO:16 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.36
FEED RATE, KG/HR: 16.00
DURATION, HR: 14.00
RESIDENCE TIME IN HR: 4.50
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.73
RECYCLE GAS SPLIT, %: BOTTOM: 40.4 MIDDLE: 59.6

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 5.21
TOTAL INPUT: 105.21

OUTPUT IN KG

SPENT SHALE: 96.34
EXHAUST GAS: 0.
ANALYZER INTAKE: 10.24
OIL PRODUCED: 5.57
WATER FORMED: 2.93
TOTAL OUTPUT: 115.08
% UNACCOUNTED: -9.37

BOTTOM RECYCLE GAS, KG: 69.78
MIDDLE RECYCLE GAS, KG: 103.03

GAS ANALYSIS IN MOL %

N2: 4.10
N2: 80.22
O2: 1.14
CO2: 8.45
CO: 5.45
CH4: 1.43
C2: 1.23
C3: 0.930
C4: 0.050

BTU PER SCFM: 95.54

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 2.49
% OIL 39.95
% SPENT SHALE: 44.82
% GAS: 8.57

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 49.39
GAS: 8.98

YIELD, % OF F.A: 68.30

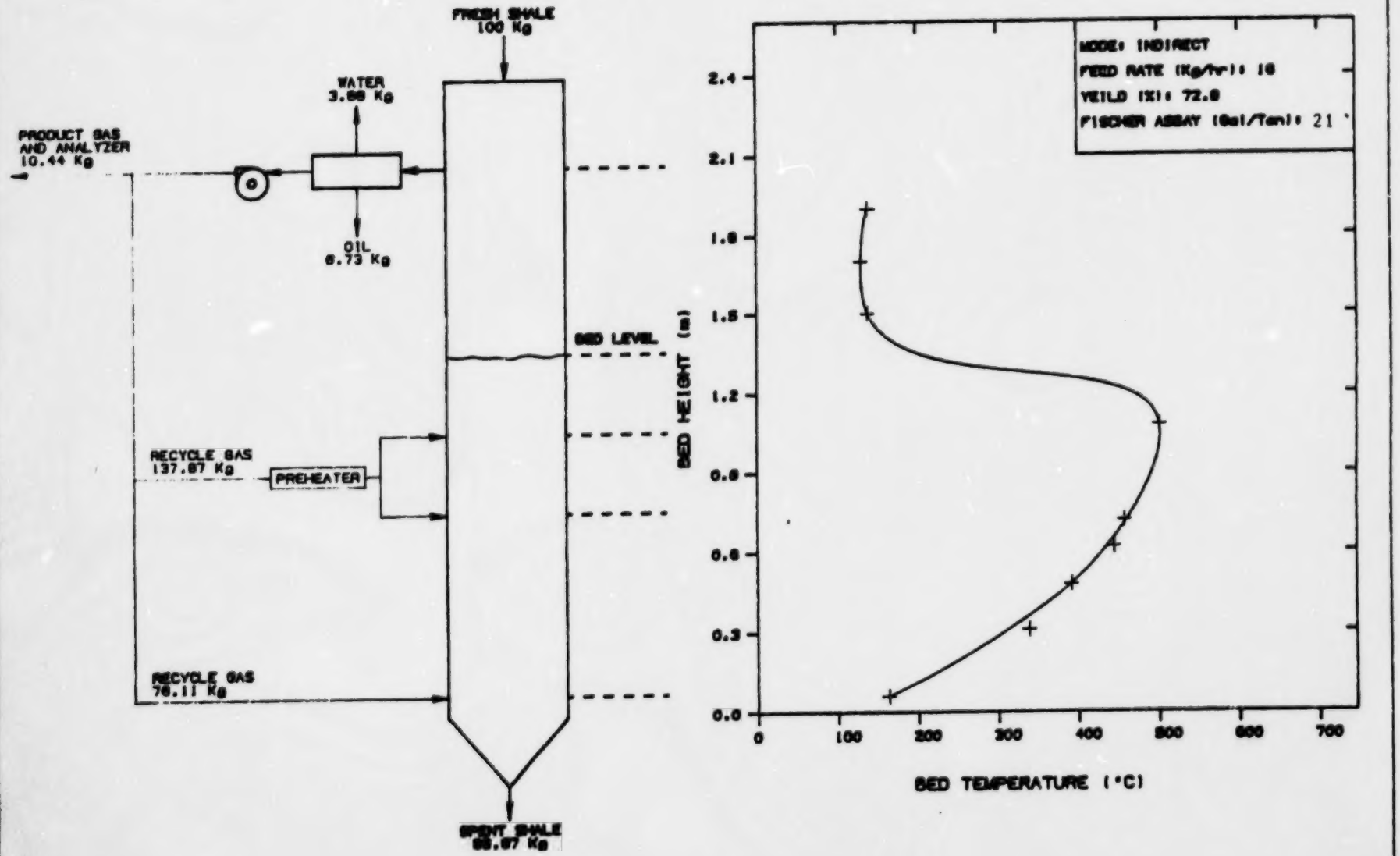


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 17

EXPERIMENT NO:17 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.43
FEED RATE, KG/HR: 16.00
DURATION, HR: 16.00
RESIDENCE TIME IN HR: 4.73
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.14
RECYCLE GAS SPLIT, %: BOTTOM: 35.6 MIDDLE: 64.4

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.57
TOTAL INPUT: 100.57

OUTPUT IN KG

SPENT SHALE: 88.87
EXHAUST GAS: 0.
ANALYZER INTAKE: 10.64
OIL PRODUCED: 6.73
WATER FORMED: 3.88
TOTAL OUTPUT: 109.91
% UNACCOUNTED: -9.29

BOTTOM RECYCLE GAS, KG: 76.11
MIDDLE RECYCLE GAS, KG: 137.07

GAS ANALYSIS IN MOL %

H2: 3.11
N2: 81.52
O2: 1.50
CO2: 6.61
CO: 3.35
CH4: 1.11
C2: 1.48
C3: 1.270
C4: 0.080

BTU PER SCFM: 95.00

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 2.69
% OIL 50.46
% SPENT SHALE: 36.12
% GAS: 6.57

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 62.15
GAS: 6.22

YIELD, % OF F.A: 72.80

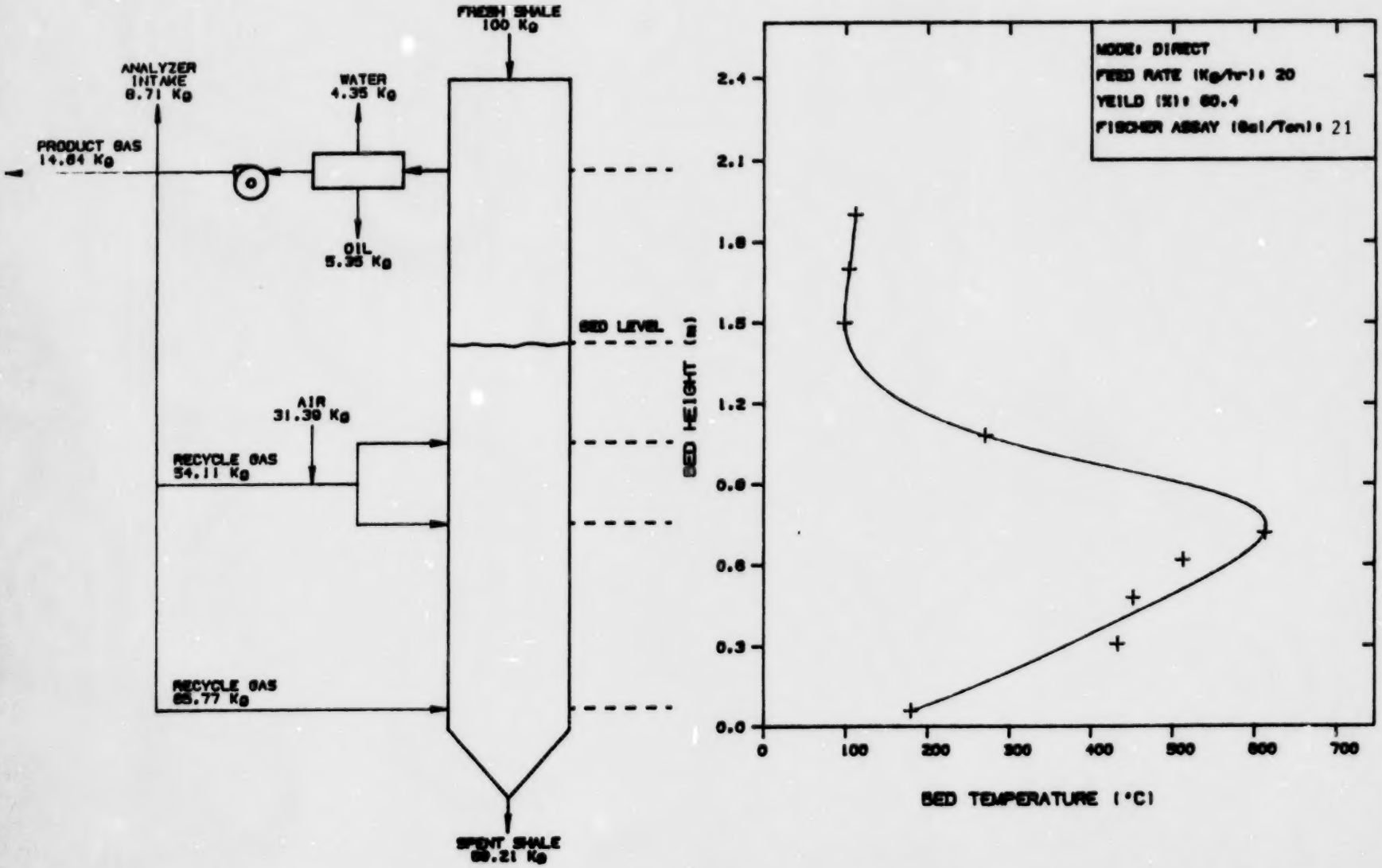


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 18

EXPERIMENT NO:18 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.43
FEED RATE, KG/HR: 20.00
DURATION, HR: 13.00
RESIDENCE TIME IN HR: 3.78
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.20
RECYCLE GAS SPLIT, % : BOTTOM: 54.9 MIDDLE: 45.1

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 31.39
AIR BOTTOM: 0.
ACCUM/DEPLE: -0.56
TOTAL INPUT: 130.82

OUTPUT IN KG

SPENT SHALE: 89.21
EXHAUST GAS: 14.64
ANALYZER INTAKE: 0.71
OIL PRODUCED: 5.35
WATER FORMED: 4.35
TOTAL OUTPUT: 122.25
% UNACCOUNTED: 6.55

BOTTOM RECYCLE GAS, KG: 65.77
MIDDLE RECYCLE GAS, KG: 54.11

GAS ANALYSIS IN MOL %

H2: 1.50
N2: 79.44
O2: 0.94
CO2: 10.92
CO: 4.64
CH4: 0.52
C2: 0.39
C3: 1.580
C4: 0.070

BTU PER SCFM: 77.53

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 2.02
% OIL 40.69
% SPENT SHALE: 44.86
% GAS: 9.99

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 49.64
GAS: 11.01

YIELD, % OF F.A: 60.40

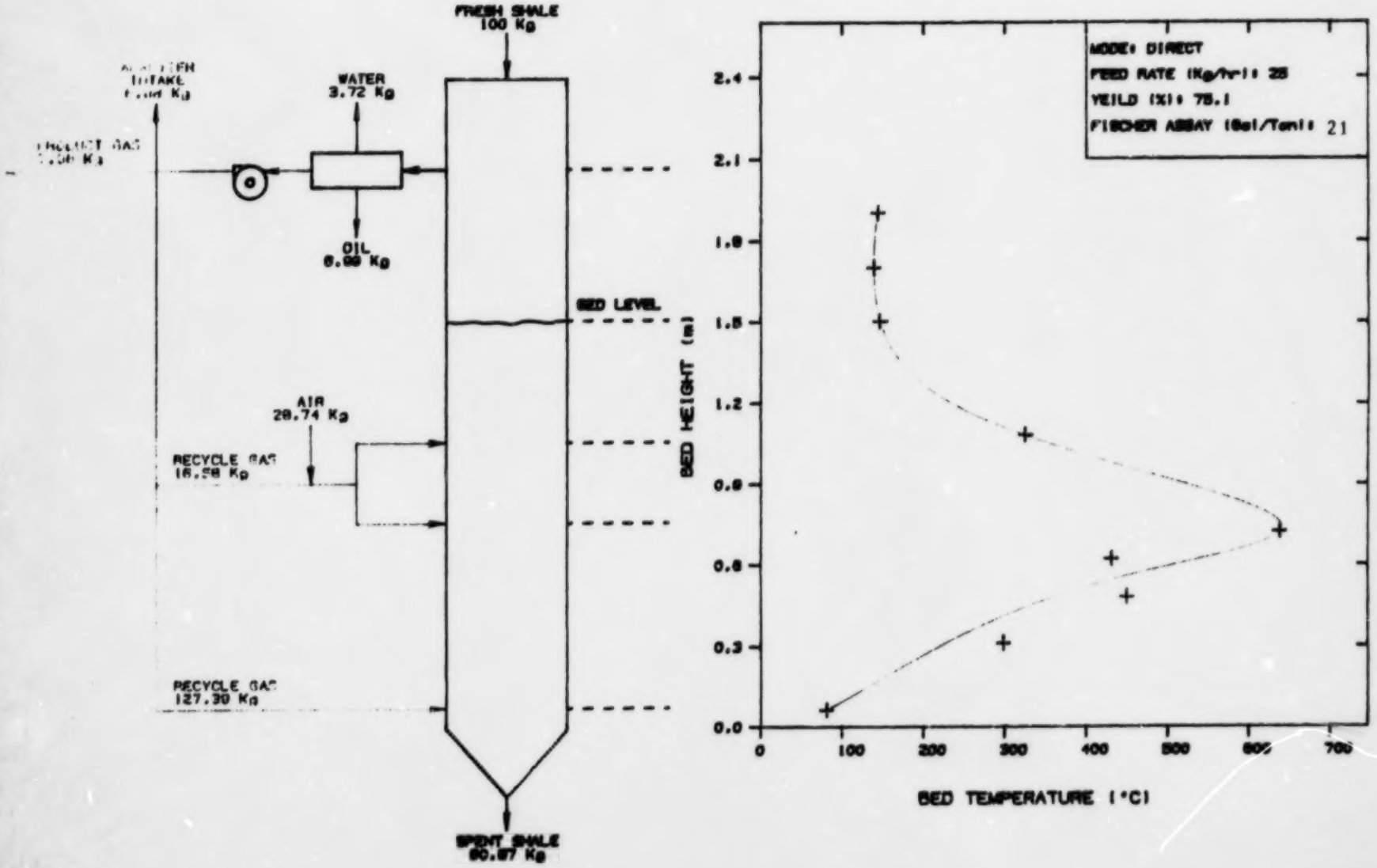


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 20

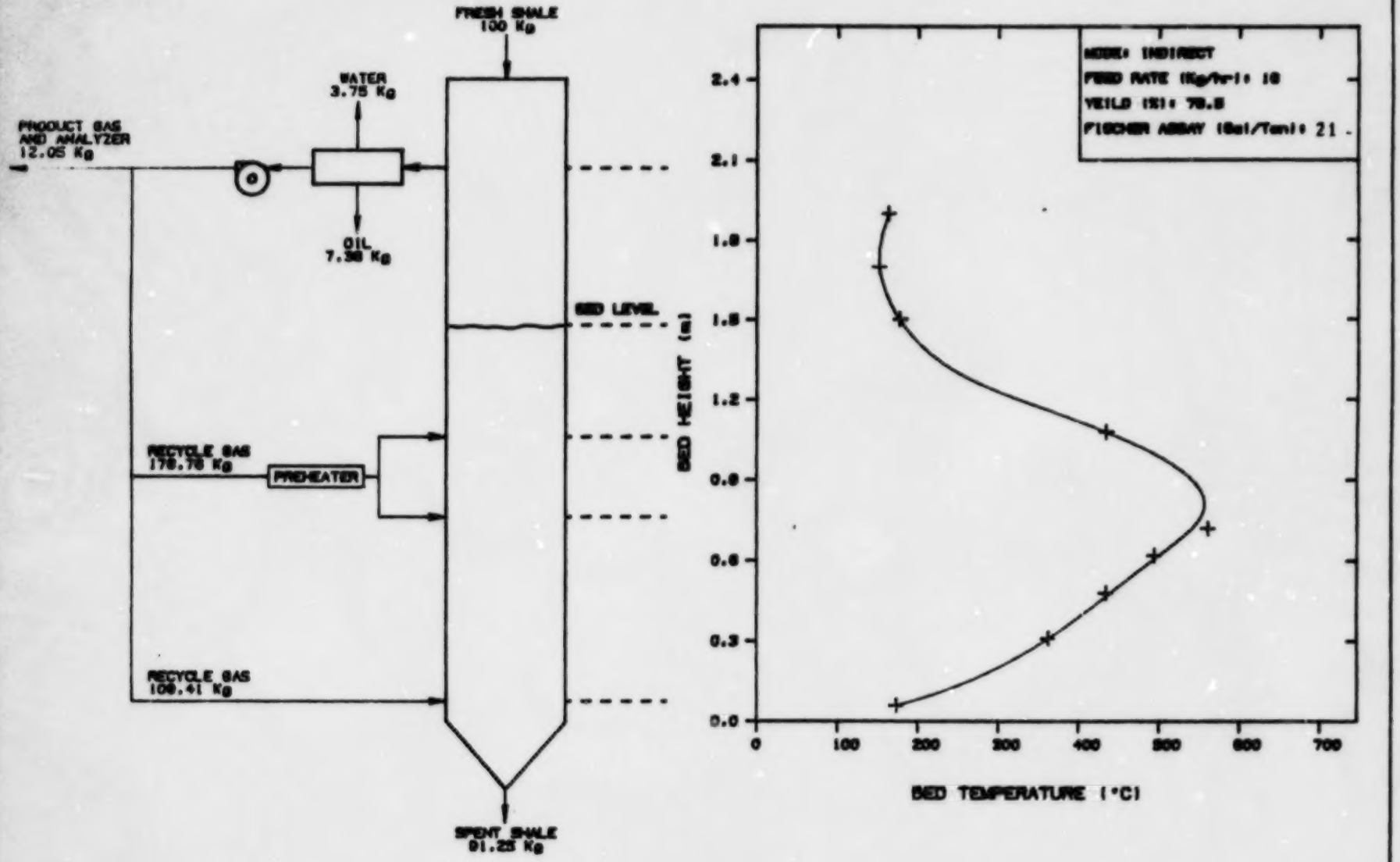


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 21

EXPERIMENT NO:20 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.51
FEED RATE, KG/HR: 25.00
DURATION, HR: 17.00
RESIDENCE TIME IN HR: 3.20
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.44
RECYCLE GAS SPLIT, % : BOTTOM: 88.5 MIDDLE: 11.5

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 28.74
AIR BOTTOM: 0.
ACCUM/DEPLE: 1.72
TOTAL INPUT: 130.46

OUTPUT IN KG

SPENT SHALE: 90.87
EXHAUST GAS: 7.96
ANALYZER INTAKE: 6.98
OIL PRODUCED: 6.99
WATER FORMED: 3.72
TOTAL OUTPUT: 116.52
% UNACCOUNTED: 10.69

BOTTOM RECYCLE GAS, KG: 127.39
MIDDLE RECYCLE GAS, KG: 16.58

GAS ANALYSIS IN MOL %

H2: 1.90
N2: 75.68
O2: 0.
CO2: 11.80
CO: 7.81
CH4: 0.39
C2: 0.43
C3: 1.890
C4: 0.100

BTU PER SCFM: 98.22

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: -1.14
% OIL 51.83
% SPENT SHALE: 40.83
% GAS: 8.19

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 63.39
GAS: 8.71

YIELD, % OF F.A: 78.10

EXPERIMENT NO:21 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.48
FEED RATE, KG/HR: 16.00
DURATION, HR: 14.00
RESIDENCE TIME IN HR: 4.89
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.86
RECYCLE GAS SPLIT, %: BOTTOM: 38.2 MIDDLE: 61.8

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.
TOTAL INPUT: 100.00

OUTPUT IN KG

SPENT SHALE: 91.25
EXHAUST GAS: 0.
ANALYZER INTAKE: 12.05
OIL PRODUCED: 7.38
WATER FORMED: 3.75
TOTAL OUTPUT: 114.43
% UNACCOUNTED: -14.43

BOTTOM RECYCLE GAS, KG: 109.41
MIDDLE RECYCLE GAS, KG: 176.76

GAS ANALYSIS IN MOL %

H2: 1.76
N2: 82.82
O2: 1.49
CO2: 6.99
CO: 2.67
CH4: 1.83
C2: 2.24
C3: 0.180
C4: 0.050

BTU PER SCFM: 79.68

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: -0.56
% OIL 55.64
% SPENT SHALE: 38.98
% GAS: 6.85

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 68.09
GAS: 6.02

YIELD, % OF F.A: 70.50

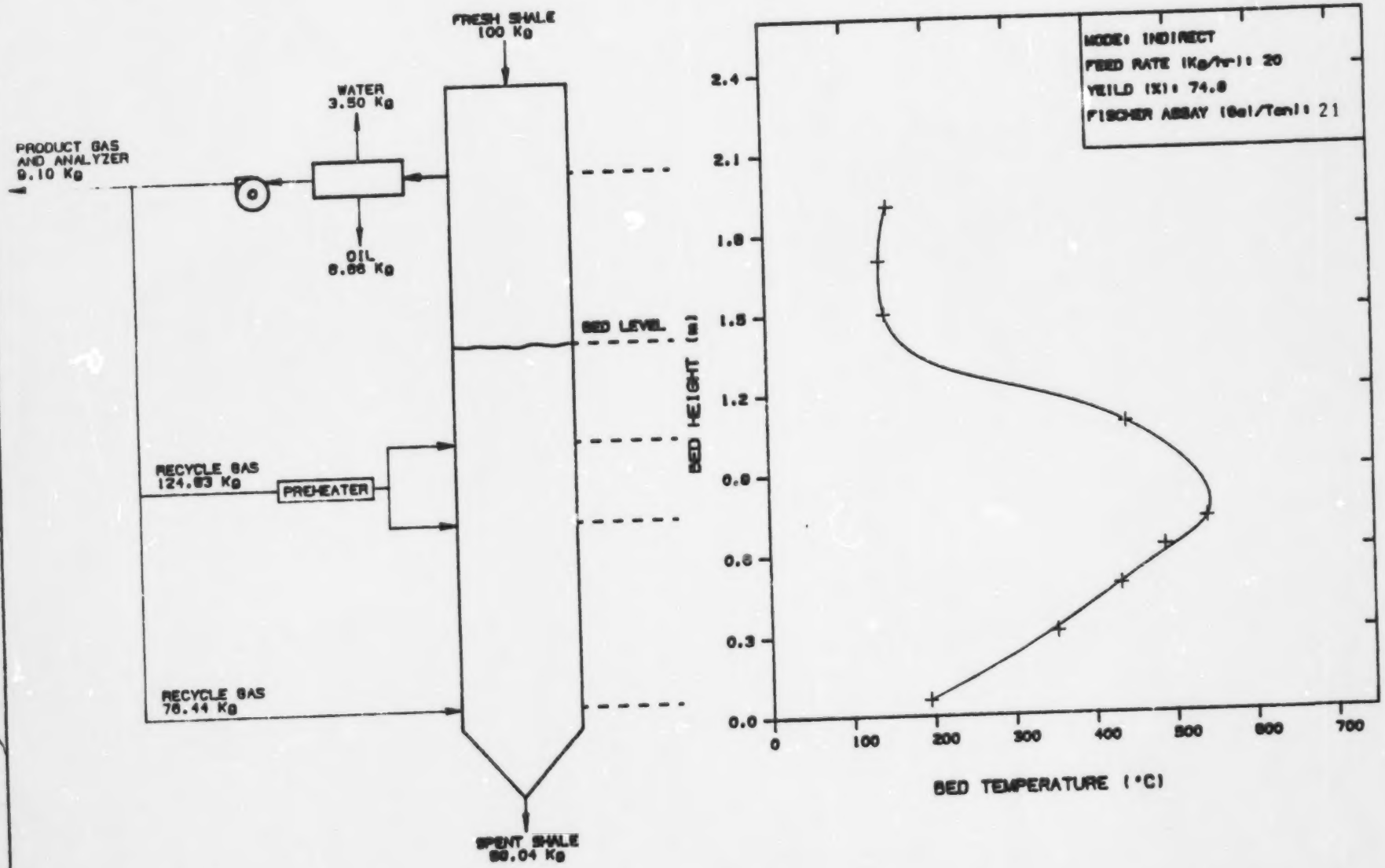


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 22

EXPERIMENT NO:22 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.43
FEED RATE, KG/HR: 20.00
DURATION, HR: 14.00
RESIDENCE TIME IN HR: 3.78
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.01
RECYCLE GAS SPLIT, %: BOTTOM: 38.0 MIDDLE: 62.0

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -1.04
TOTAL INPUT: 98.96

OUTPUT IN KG

SPENT SHALE: 89.04
EXHAUST GAS: 0.
ANALYZER INTAKE: 9.10
OIL PRODUCED: 6.66
WATER FORMED: 3.50
TOTAL OUTPUT: 108.30
% UNACCOUNTED: -9.44

BOTTOM RECYCLE GAS, KG: 76.44
MIDDLE RECYCLE GAS, KG: 124.83

GAS ANALYSIS IN MOL %

H2: 4.00
N2: 80.72
O2: 1.31
CO2: 6.03
CO: 3.40
CH4: 1.70
C2: 2.49
C3: 0.280
C4: 0.070

BTU PER SCFM: 96.49

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 2.72
% OIL 50.78
% SPENT SHALE: 38.91
% GAS: 5.38

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 62.07
GAS: 5.71

YIELD, % OF F.A: 74.90

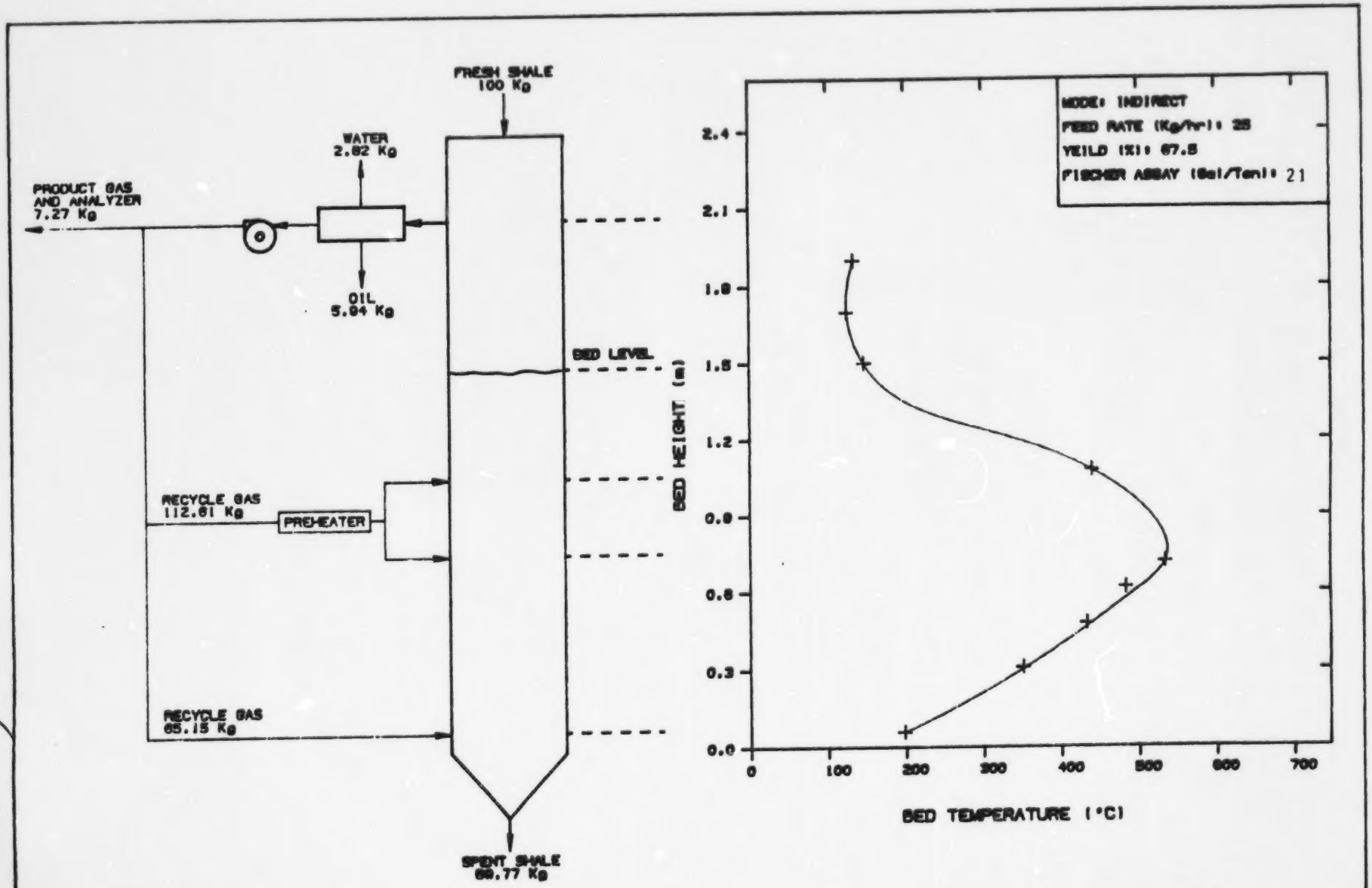


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 23

EXPERIMENT NO:23 SHALE NO: 1

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.49
FEED RATE, KG/HR: 25.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 3.15
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.78
RECYCLE GAS SPLIT, %: BOTTOM: 36.7 MIDDLE: 63.3

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.49
TOTAL INPUT: 100.49

OUTPUT IN KG

SPENT SHALE: 89.77
EXHAUST GAS: 0.
ANALYZER INTAKE: 7.27
OIL PRODUCED: 5.94
WATER FORMED: 2.82
TOTAL OUTPUT: 105.79
% UNACCOUNTED: -5.28

BOTTOM RECYCLE GAS, KG: 65.15
MIDDLE RECYCLE GAS, KG: 112.61

GAS ANALYSIS IN MOL %

H2: 4.10
N2: 81.17
O2: 1.31
CO2: 5.48
CO: 3.61
CH4: 1.34
C2: 2.37
C3: 0.500
C4: 0.120

BTU PER SCFM: 99.20

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 3.24
% OIL 44.57
% SPENT SHALE: 44.59
% GAS: 3.98

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 54.78
GAS: 4.62

YIELD, % OF F.A: 67.50

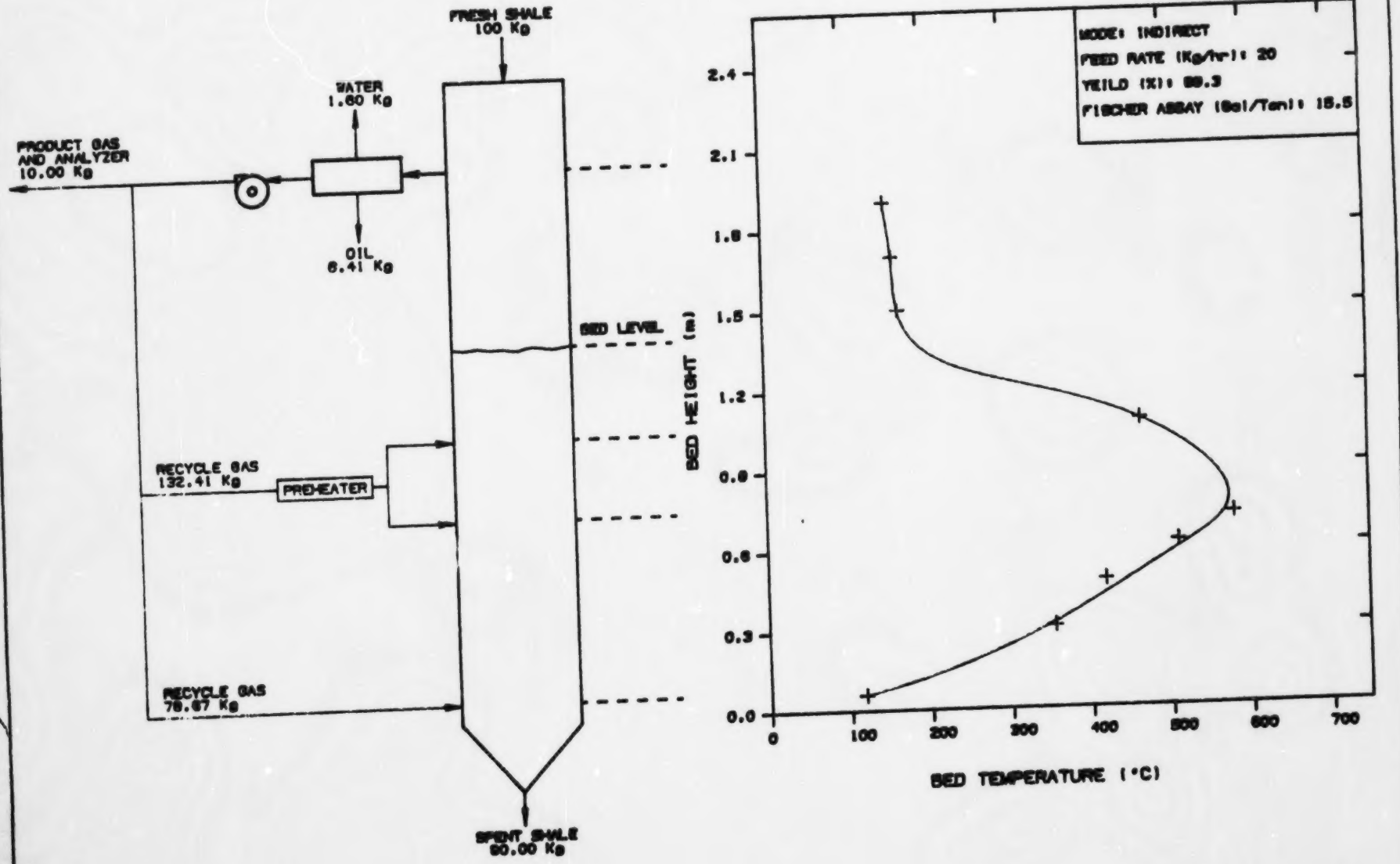


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 27

EXPERIMENT NO:27 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.41
FEED RATE, KG/HR: 20.00
DURATION, HR: 14.00
RESIDENCE TIME IN HR: 3.73
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.11
RECYCLE GAS SPLIT, %: BOTTOM: 37.3 MIDDLE: 62.7

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.52
TOTAL INPUT: 100.52

OUTPUT IN KG

SPENT SHALE: 90.00
EXHAUST GAS: 0.
ANALYZER INTAKE: 10.00
OIL PRODUCED: 6.41
WATER FORMED: 1.60
TOTAL OUTPUT: 108.02
% UNACCOUNTED: -7.46

BOTTOM RECYCLE GAS, KG: 78.67
MIDDLE RECYCLE GAS, KG: 132.41

GAS ANALYSIS IN MOL %

H2: 4.09
N2: 77.29
O2: 1.57
CO2: 9.52
CO: 2.85
CH4: 1.67
C2: 2.62
C3: 0.380
C4: 0.110

BTU PER SCFM: 99.18

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: -2.39
% OIL 55.15
% SPENT SHALE: 42.56
% GAS: 8.37

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 68.70
GAS: 7.33

YIELD, % OF F.A: 89.80

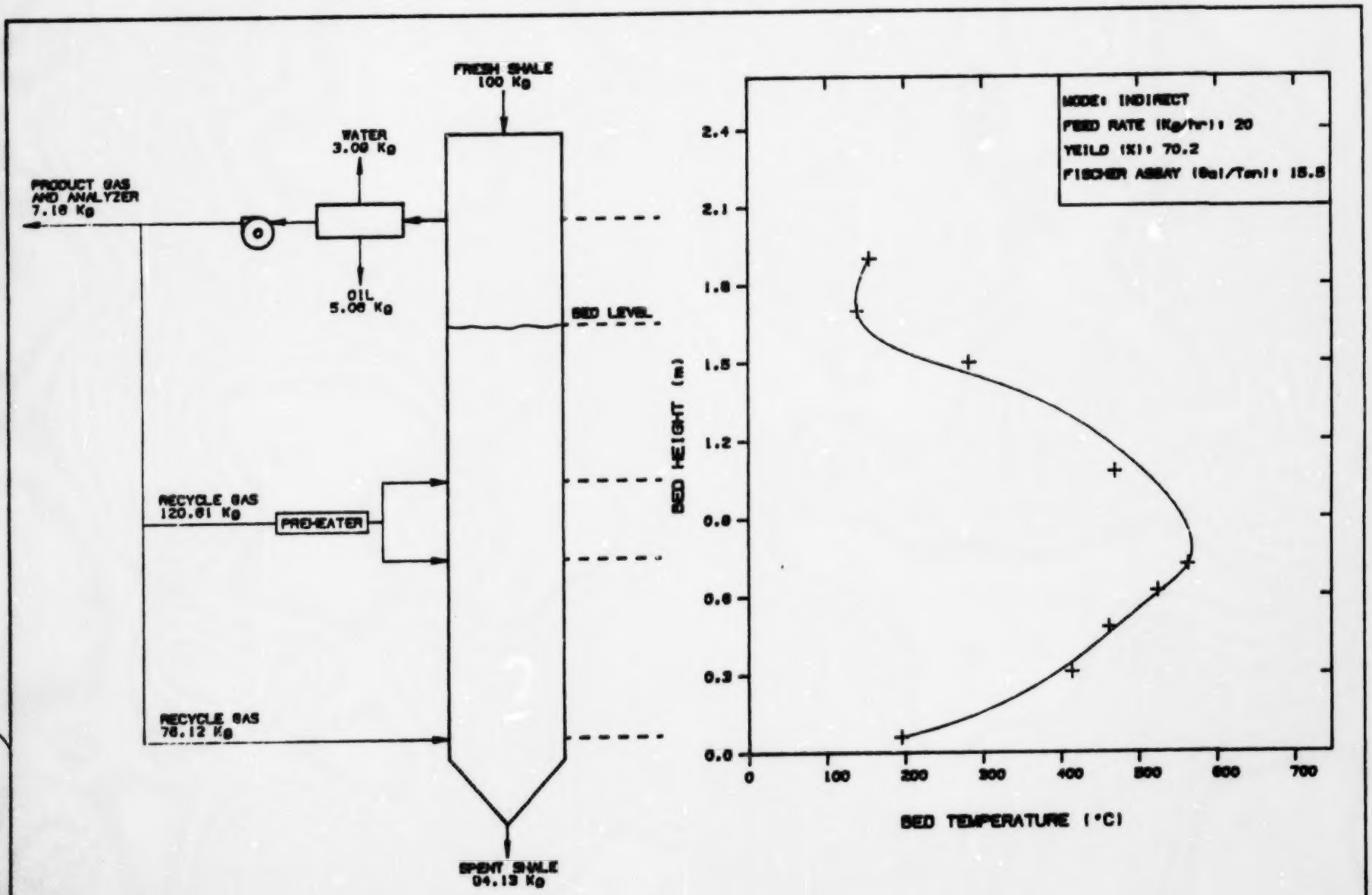


FIG 8 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 28

EXPERIMENT NO:20 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.53
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.05
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.97
RECYCLE GAS SPLIT, %: BOTTOM: 38.7 MIDDLE: 61.3

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -2.43
TOTAL INPUT: 97.57

OUTPUT IN KG

SPENT SHALE: 94.13
EXHAUST GAS: 0.
ANALYZER INTAKE: 7.16
OIL PRODUCED: 5.06
WATER FORMED: 3.09
TOTAL OUTPUT: 109.43
% UNACCOUNTED: -12.16

BOTTOM RECYCLE GAS, KG: 76.12
MIDDLE RECYCLE GAS, KG: 120.61

GAS ANALYSIS IN MOL %

H2: 4.05
N2: 74.69
O2: 1.73
CO2: 9.30
CO: 3.20
CH4: 5.24
C2: 1.60
C3: 0.290
C4: 0.100

BTU PER SCFM: 117.72

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 4.26
% OIL 44.85
% SPENT SHALE: 38.98
% GAS: 6.89

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 56.35
GAS: 6.52

YIELD, % OF F.A: 70.20

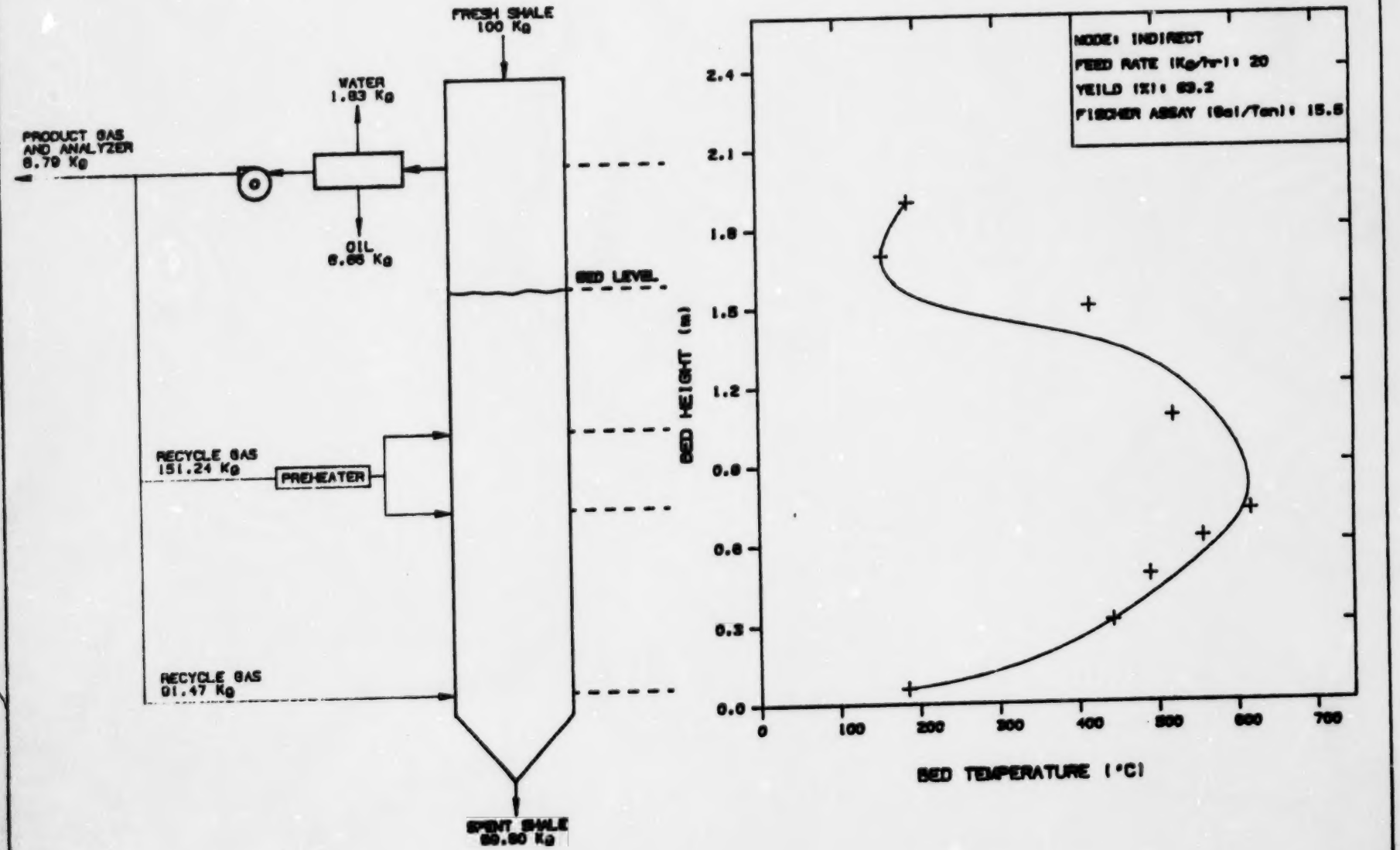


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 29

EXPERIMENT NO:29 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.60
FEED RATE, KG/HR: 20.00
DURATION, HR: 15.00
RESIDENCE TIME IN HR: 4.22
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.43
RECYCLE GAS SPLIT, %: BOTTOM: 37.7 MIDDLE: 62.3

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -0.49
TOTAL INPUT: 99.51

OUTPUT IN KG

SPENT SHALE: 89.80
EXHAUST GAS: 0.
ANALYZER INTAKE: 8.79
OIL PRODUCED: 6.66
WATER FORMED: 1.83
TOTAL OUTPUT: 107.08
% UNACCOUNTED: -7.60

BOTTOM RECYCLE GAS, KG: 91.47
MIDDLE RECYCLE GAS, KG: 151.24

GAS ANALYSIS IN MOL %

H2: 4.00
N2: 76.29
O2: 2.07
CO2: 10.53
CO: 2.85
CH4: 2.03
C2: 1.88
C3: 0.180
C4: 0.170

BTU PER SCFM: 88.34

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: -0.83
% OIL 57.87
% SPENT SHALE: 37.91
% GAS: 7.20

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 68.45
GAS: 5.77

YIELD, % OF F.A: 93.20

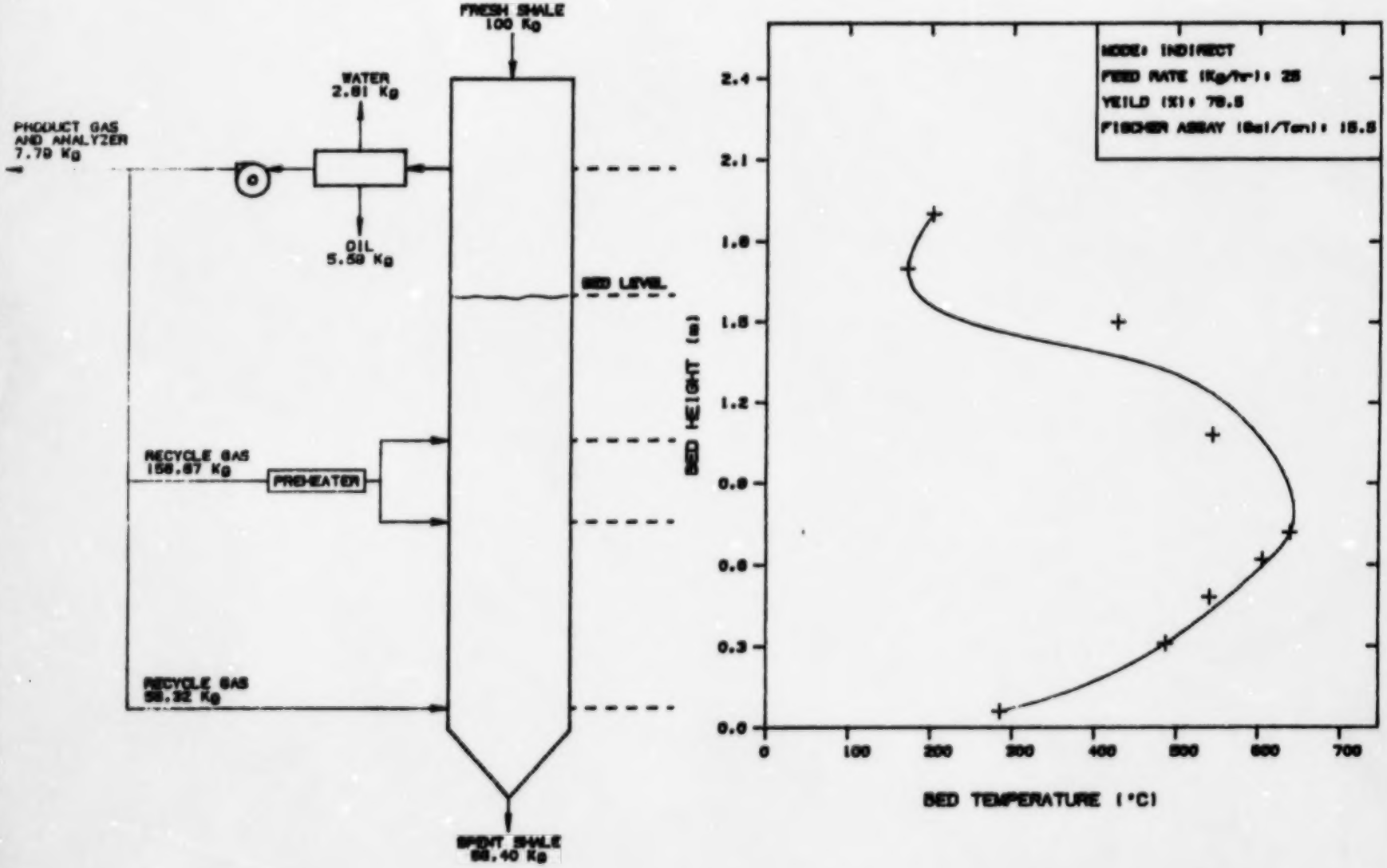


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 30

EXPERIMENT NO:30 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.61
FEED RATE, KG/HR: 25.00
DURATION, HR: 11.00
RESIDENCE TIME IN HR: 3.41
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.15
RECYCLE GAS SPLIT, %: BOTTOM: 27.1 MIDDLE: 72.9

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -0.53
TOTAL INPUT: 99.47

OUTPUT IN KG

SPENT SHALE: 88.40
EXHAUST GAS: 0.
ANALYZER INTAKE: 7.80
OIL PRODUCED: 5.59
WATER FORMED: 2.81
TOTAL OUTPUT: 104.60
% UNACCOUNTED: -5.16

BOTTOM RECYCLE GAS, KG: 58.37
MIDDLE RECYCLE GAS, KG: 156.99

GAS ANALYSIS IN MOL %

H2: 2.76
N2: 75.56
O2: 2.39
CO2: 12.62
CO: 2.65
CH4: 1.77
C2: 1.90
C3: 0.260
C4: 0.090

BTU PER SCFM: 80.34

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 3.28
% OIL 48.57
% SPENT SHALE: 35.64
% GAS: 6.85

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 57.98
GAS: 4.88

YIELD, % OF F.A: 78.80

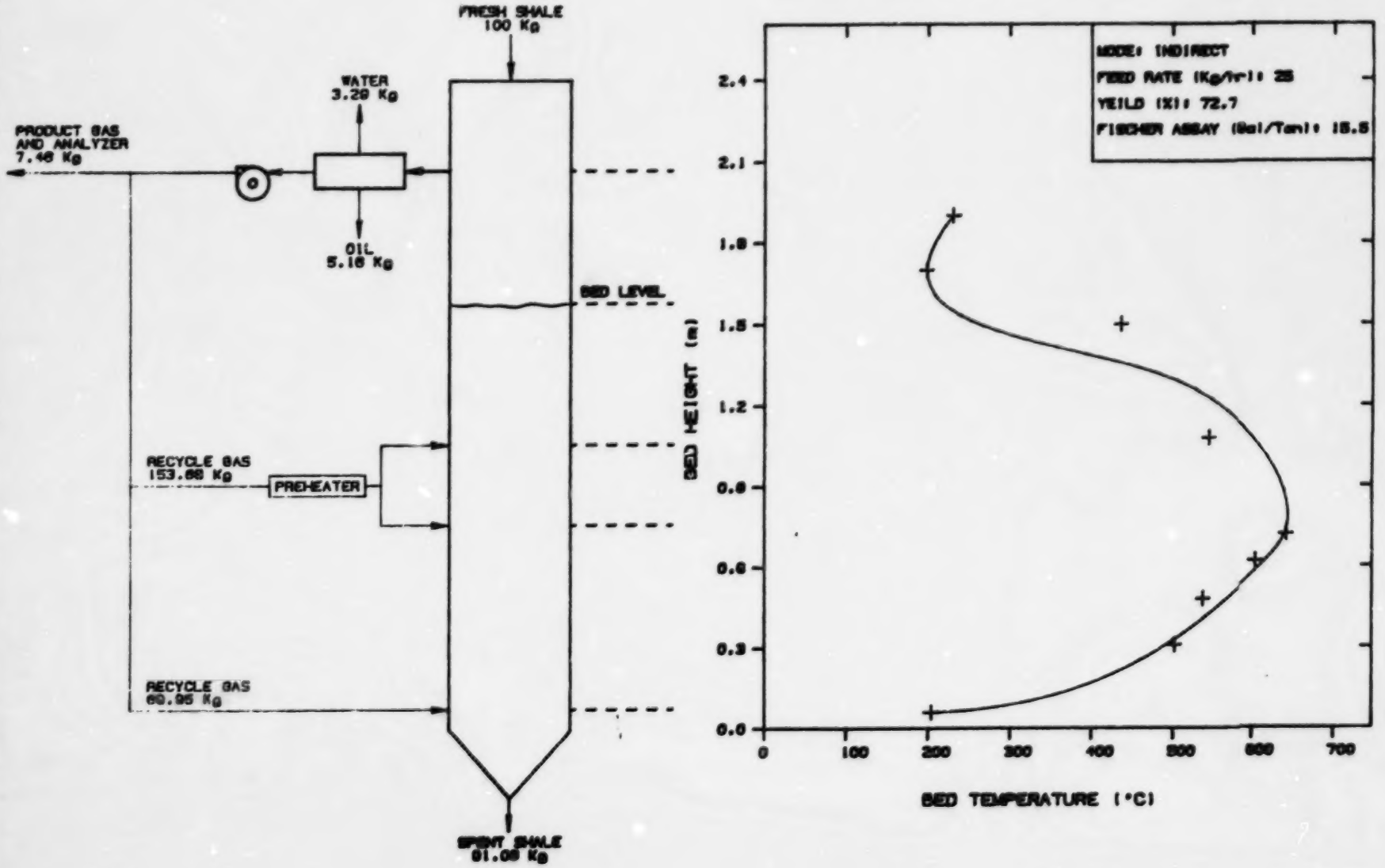


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 31

EXPERIMENT NO:31 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.58
FEED RATE, KG/HR: 25.00
DURATION, HR: 14.00
RESIDENCE TIME IN HR: 3.34
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.24
RECYCLE GAS SPLIT, %: BOTTOM: 31.3 MIDDLE: 68.7

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: -0.83
TOTAL INPUT: 99.17

OUTPUT IN KG

SPENT SHALE: 91.06
EXHAUST GAS: 0.
ANALYZER INTAKE: 7.46
OIL PRODUCED: 5.16
WATER FORMED: 3.29
TOTAL OUTPUT: 106.96
% UNACCOUNTED: -7.86

BOTTOM RECYCLE GAS, KG: 69.95
MIDDLE RECYCLE GAS, KG: 153.68

GAS ANALYSIS IN MOL %

H2: 4.00
N2: 75.56
O2: 3.68
CO2: 11.54
CO: 1.97
CH4: 1.55
C2: 1.42
C3: 0.190
C4: 0.390

BTU PER SCFM: 69.40

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 5.35
% OIL 44.95
% SPENT SHALE: 35.35
% GAS: 5.81

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 54.00
GAS: 3.82

YIELD, % OF F.A: 72.70

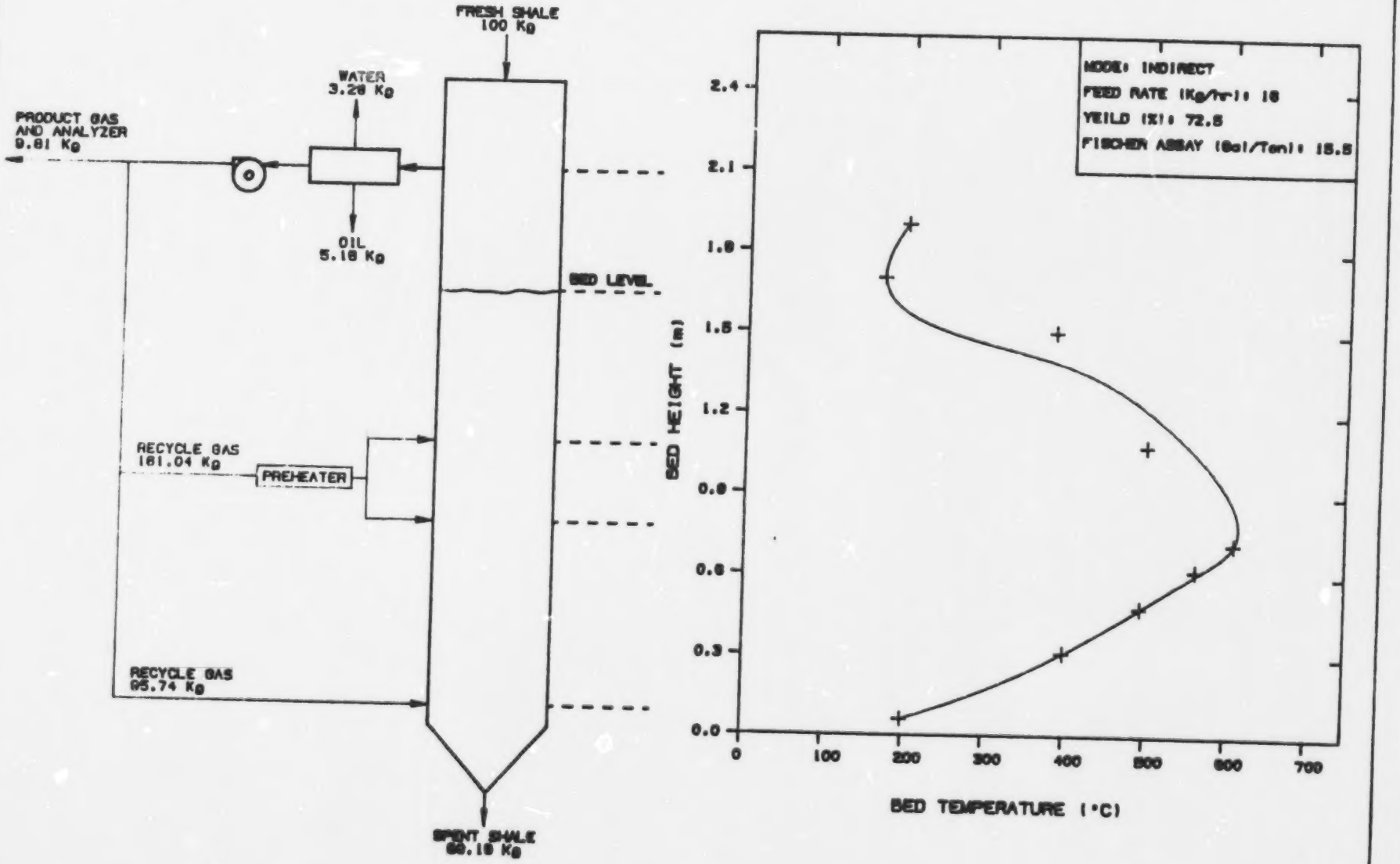


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 32

EXPERIMENT NO:32 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.62
FEED RATE, KG/HR: 16.00
DURATION, HR: 13.00
RESIDENCE TIME IN HR: 5.36
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.57
RECYCLE GAS SPLIT, %: BOTTOM: 37.3 MIDDLE: 62.7

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 2.11
TOTAL INPUT: 102.11

OUTPUT IN KG

SPENT SHALE: 89.18
EXHAUST GAS: 0.
ANALYZER INTAKE: 9.81
OIL PRODUCED: 5.18
WATER FORMED: 3.28
TOTAL OUTPUT: 107.46
% UNACCOUNTED: -5.24

BOTTOM RECYCLE GAS, KG: 95.74
MIDDLE RECYCLE GAS, KG: 161.04

GAS ANALYSIS IN MOL %

H2: 2.50
N2: 77.14
O2: 2.49
CO2: 11.45
CO: 2.12
CH4: 2.23
C2: 1.72
C3: 0.170
C4: 0.110

BTU PER SCFM: 77.72

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 3.42
% OIL 43.87
% SPENT SHALE: 36.34
% GAS: 7.59

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 53.53
GAS: 5.43

YIELD, % OF F.A: 72.80

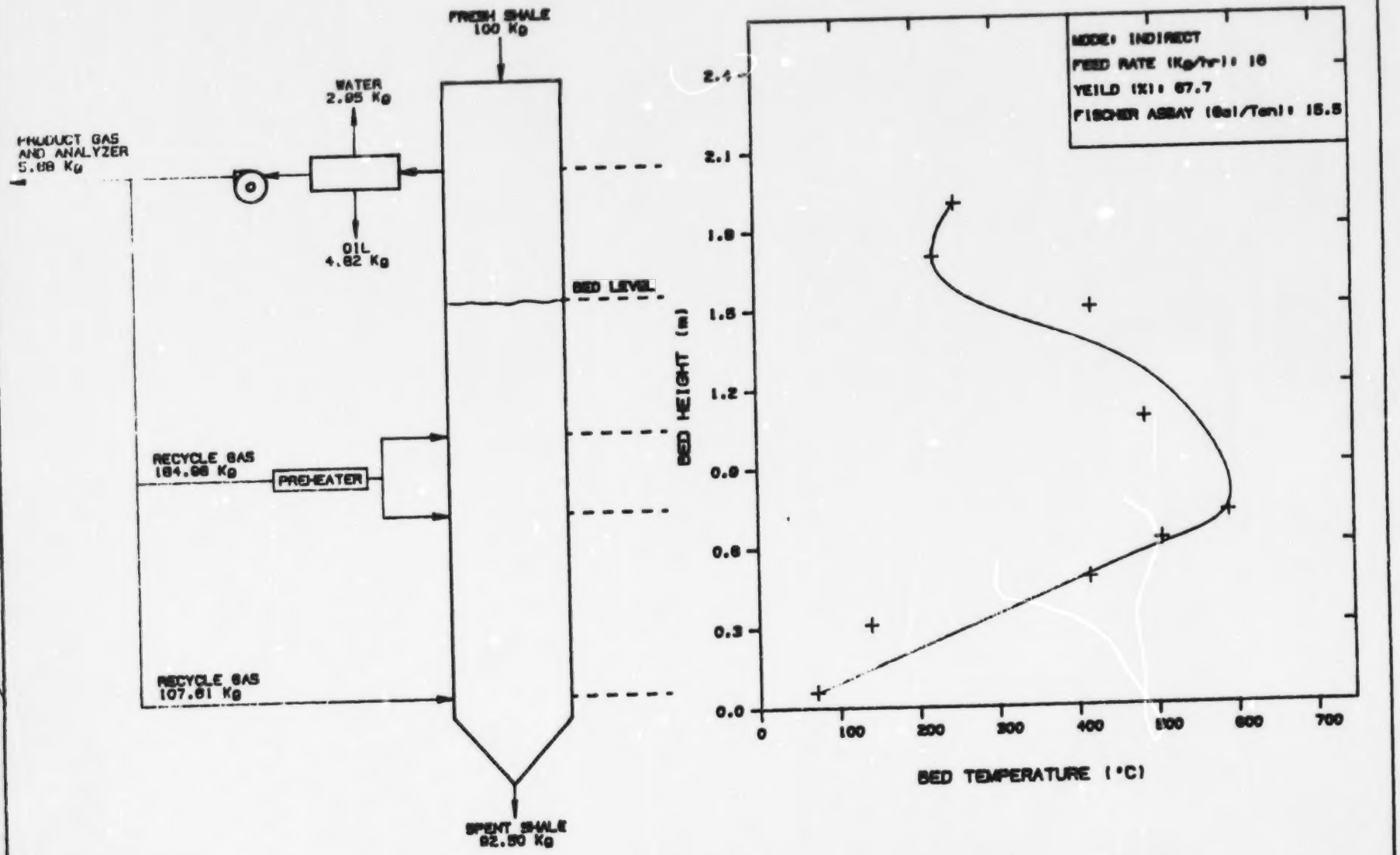


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 34

EXPERIMENT NO:34 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.57
FEED RATE, KG/HR: 16.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 5.19
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.93
RECYCLE GAS SPLIT, %: BOTTOM: 36.8 MIDDLE: 63.2

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 3.04
TOTAL INPUT: 103.04

OUTPUT IN KG

SPENT SHALE: 92.50
EXHAUST GAS: 0.
ANALYZER INTAKE: 5.68
OIL PRODUCED: 4.82
WATER FORMED: 2.95
TOTAL OUTPUT: 105.95
% UNACCOUNTED: -2.82

BOTTOM RECYCLE GAS, KG: 107.61
MIDDLE RECYCLE GAS, KG: 184.98

GAS ANALYSIS IN MOL %

N2: 7.49
N2: 73.27
O2: 0.59
CO2: 9.65
CO: 2.85
CH4: 1.40
C2: 2.90
C3: 1.390
C4: 0.440

BTU PER SCFM: 152.83

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 2.99
% OIL 40.46
% SPENT SHALE: 38.61
% GAS: 5.93

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 50.28
GAS: 6.40

YIELD, % OF F.A: 67.70

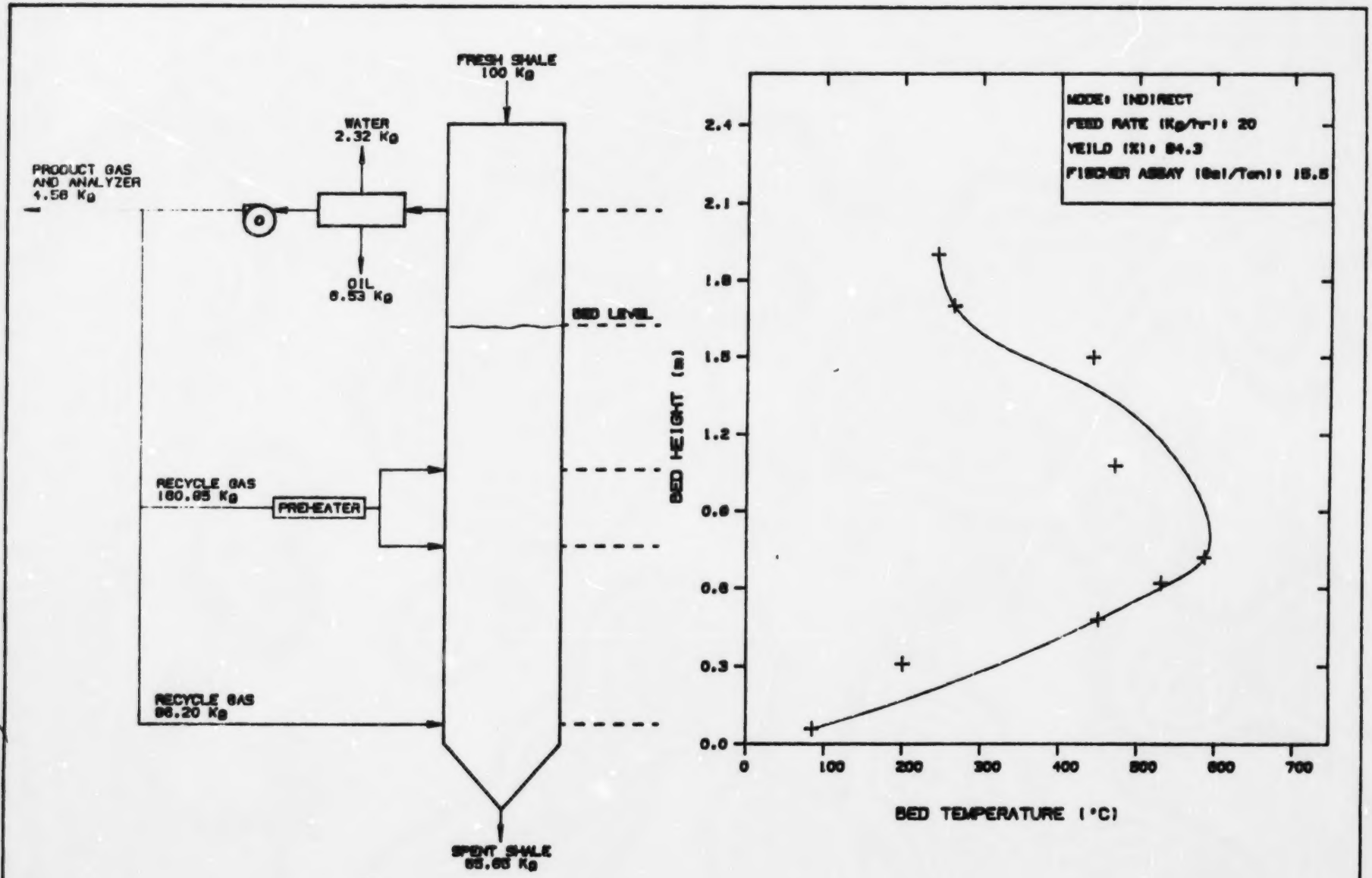


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 35

EXPERIMENT NO:35 SHALE NO: 2

MODE: INDIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.62
FEED RATE, KG/HR: 20.00
DURATION, HR: 18.00
RESIDENCE TIME IN HR: 4.28
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.47
RECYCLE GAS SPLIT, %: BOTTOM: 34.9 MIDDLE: 65.1

INPUT IN KG

FRESH SHALE: 100.00
ACCUM/DEPLE: 0.56
TOTAL INPUT: 100.56

OUTPUT IN KG

SPENT SHALE: 85.65
EXHAUST GAS: 0.
ANALYZER INTAKE: 4.56
OIL PRODUCED: 6.53
WATER FORMED: 2.32
TOTAL OUTPUT: 99.07
% UNACCOUNTED: 1.49

BOTTOM RECYCLE GAS, KG: 86.20
MIDDLE RECYCLE GAS, KG: 160.95

GAS ANALYSIS IN MOL %

H2: 6.58
N2: 75.15
O2: 0.98
CO2: 10.14
CO: 2.15
CH4: 1.17
C2: 2.28
C3: 1.150
C4: 0.400

BTU PER SCFM: 126.35

DISTRIBUTION OF ORGANIC CARBON

% UNACCOUNTED CARBON: 1.24
% OIL 56.10
% SPENT SHALE: 34.93
% GAS: 4.29

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 70.19
GAS: 4.31

YIELD, % OF F.A: 84.30

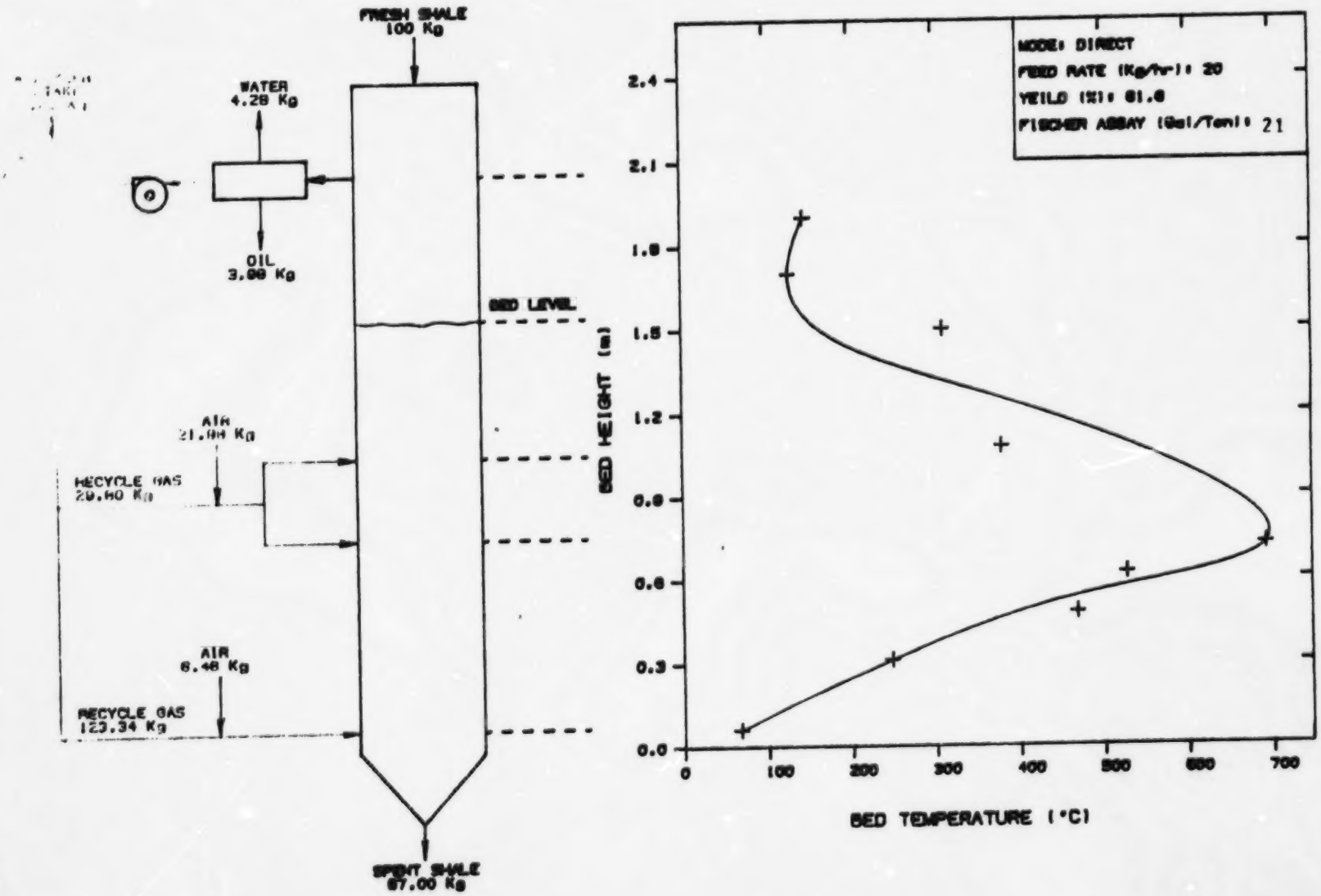


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 36

EXPERIMENT NO:36 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.55
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.10
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.53
RECYCLE GAS SPLIT, % : BOTTOM: 80.5 MIDDLE: 19.5

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 21.98
AIR BOTTOM: 6.46
ACCUM/DEPLE: -2.43
TOTAL INPUT: 126.01

OUTPUT IN KG

SPENT SHALE: 87.00
EXHAUST GAS: 27.48
ANALYZER INTAKE: 7.63
OIL PRODUCED: 4.28
WATER FORMED: 3.98
TOTAL OUTPUT: 130.87
% UNACCOUNTED: -3.46

BOTTOM RECYCLE GAS, KG: 123.34
MIDDLE RECYCLE GAS, KG: 29.80

GAS ANALYSIS IN MOL %

H2: 1.55
N2: 77.78
O2: 1.61
CO2: 18.10
CO: 1.48
CH4: 1.87
C2: 1.48
C3: 0.950
C4: 0.680

BTU PER SCFM: 99.46

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 7.96
% OIL 89.05
% SPENT SHALE: 97.31
% GAS 14.84

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 40.20
GAS: 21.40

YIELD, % OF F.A: 61.6

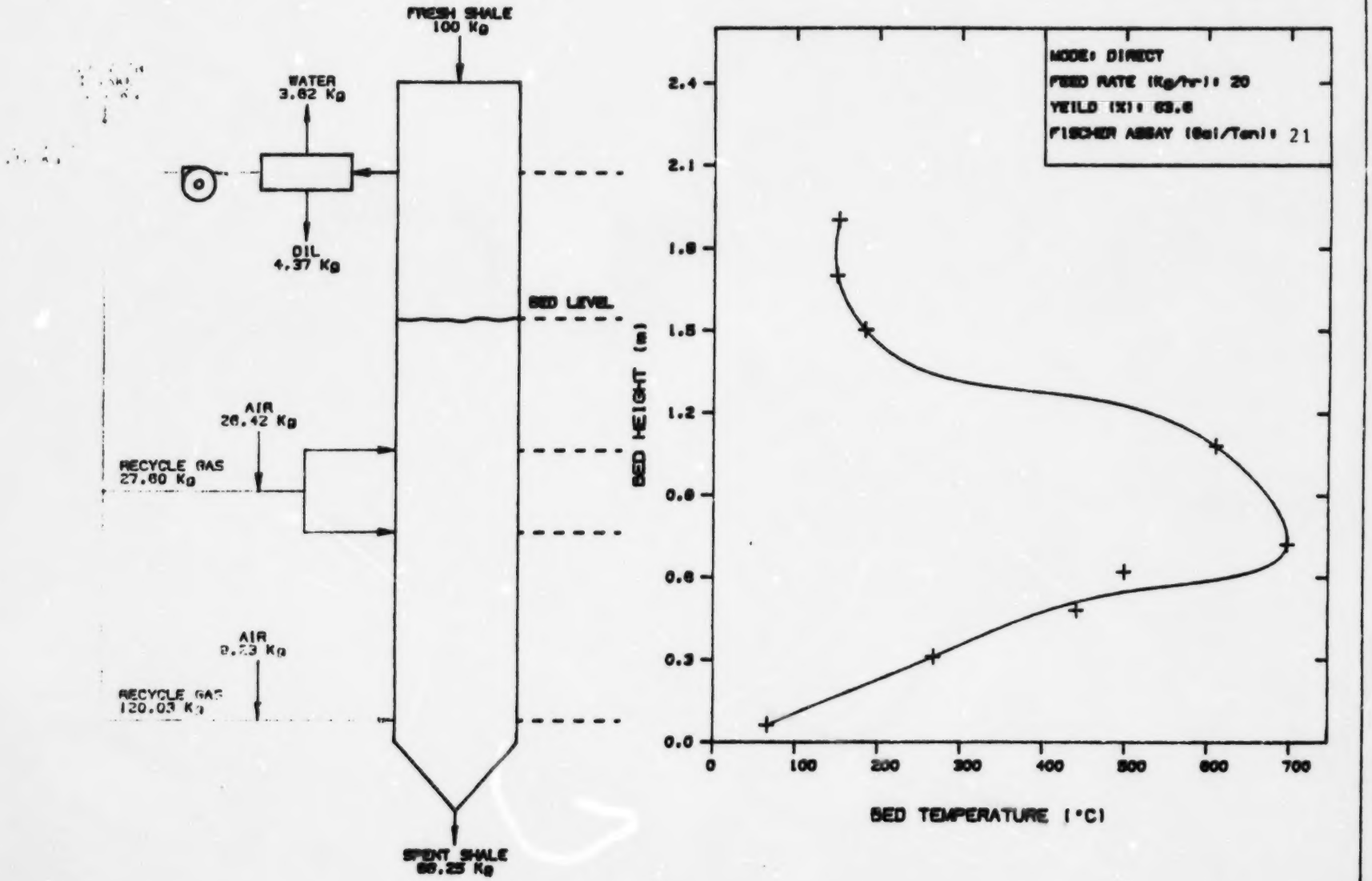


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 37

EXPERIMENT NO:37 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.62
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.02
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.48
RECYCLE GAS SPLIT, % : BOTTOM: 81.3 MIDDLE: 18.7

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 26.42
AIR BOTTOM: 9.23
ACCUM/DEPLE: 0.61
TOTAL INPUT: 136.25

OUTPUT IN KG

SPENT SHALE: 86.33
EXHAUST GAS: 18.19
ANALYZER INTAKE: 7.77
OIL PRODUCED: 4.37
WATER FORMED: 3.62
TOTAL OUTPUT: 120.28
% UNACCOUNTED: 11.73

BOTTOM RECYCLE GAS, KG: 120.03
MIDDLE RECYCLE GAS, KG: 27.60

GAS ANALYSIS IN MOL %

H2: 2.07
N2: 78.49
O2: 0.30
CO2: 14.10
CO: 1.95
CH4: 1.36
C2: 0.97
C3: 0.440
C4: 0.320

BTU PER SCFM: 67.83

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 10.43
% OIL 32.74
% SPENT SHALE: 34.93
% GAS: 10.92

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 40.18
GAS: 10.84

YIELD, % OF F.A: 83.8

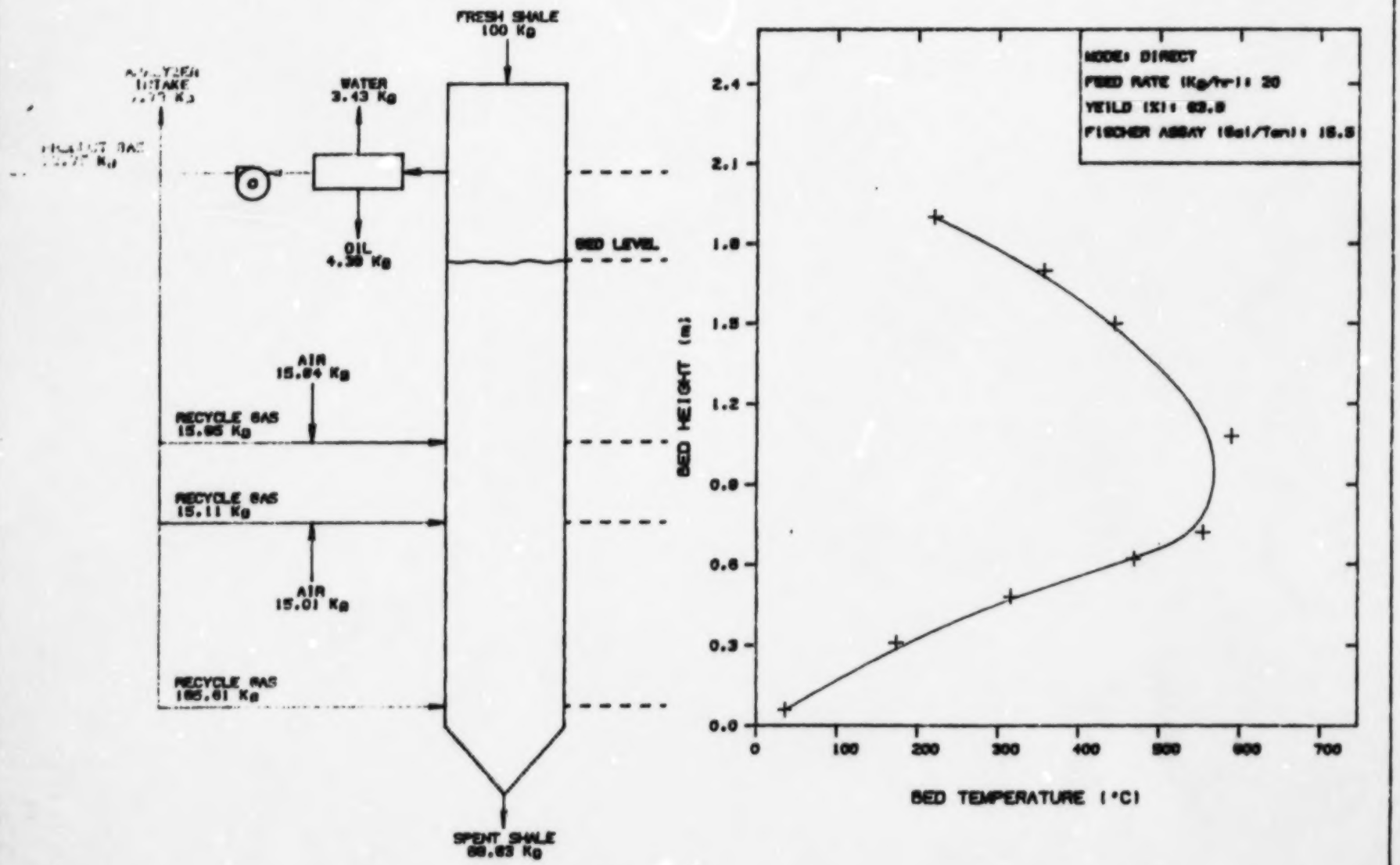


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 41

EXPERIMENT NO:41 SHALE NO: 2

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.74
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.60
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.17
RECYCLE GAS SPLIT, % : BOTTOM: 85.7 MIDDLE: 14.3

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 30.64
AIR BOTTOM: 0.
ACCUM/DEPLE: 2.43
TOTAL INPUT: 133.08

OUTPUT IN KG

SPENT SHALE: 88.83
EXHAUST GAS: 22.78
ANALYZER INTAKE: 7.73
OIL PRODUCED: 4.38
WATER FORMED: 3.43
TOTAL OUTPUT: 127.13
% UNACCOUNTED: 4.47

MID AIR SPLIT
MID AIR UPPER, KG: 15.64
MID AIR LOWER, KG: 15.01

BOTTOM RECYCLE GAS, KG: 185.61
MIDDLE RECYCLE GAS, KG: 31.06

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 15.95
LOWER, KG: 15.11

GAS ANALYSIS IN MOL %

H2: 2.26
N2: 75.58
O2: 0.
CO2: 17.42
CO: 2.22
CH4: 1.33
C2: 0.73
C3: 0.300
C4: 0.160
BTU PER SCFM: 55.63

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 2.92
% OIL 36.99
% SPENT SHALE: 36.43
% GAS: 15.84

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 46.63
GAS: 11.60

YIELD, % OF F.A: 63.90

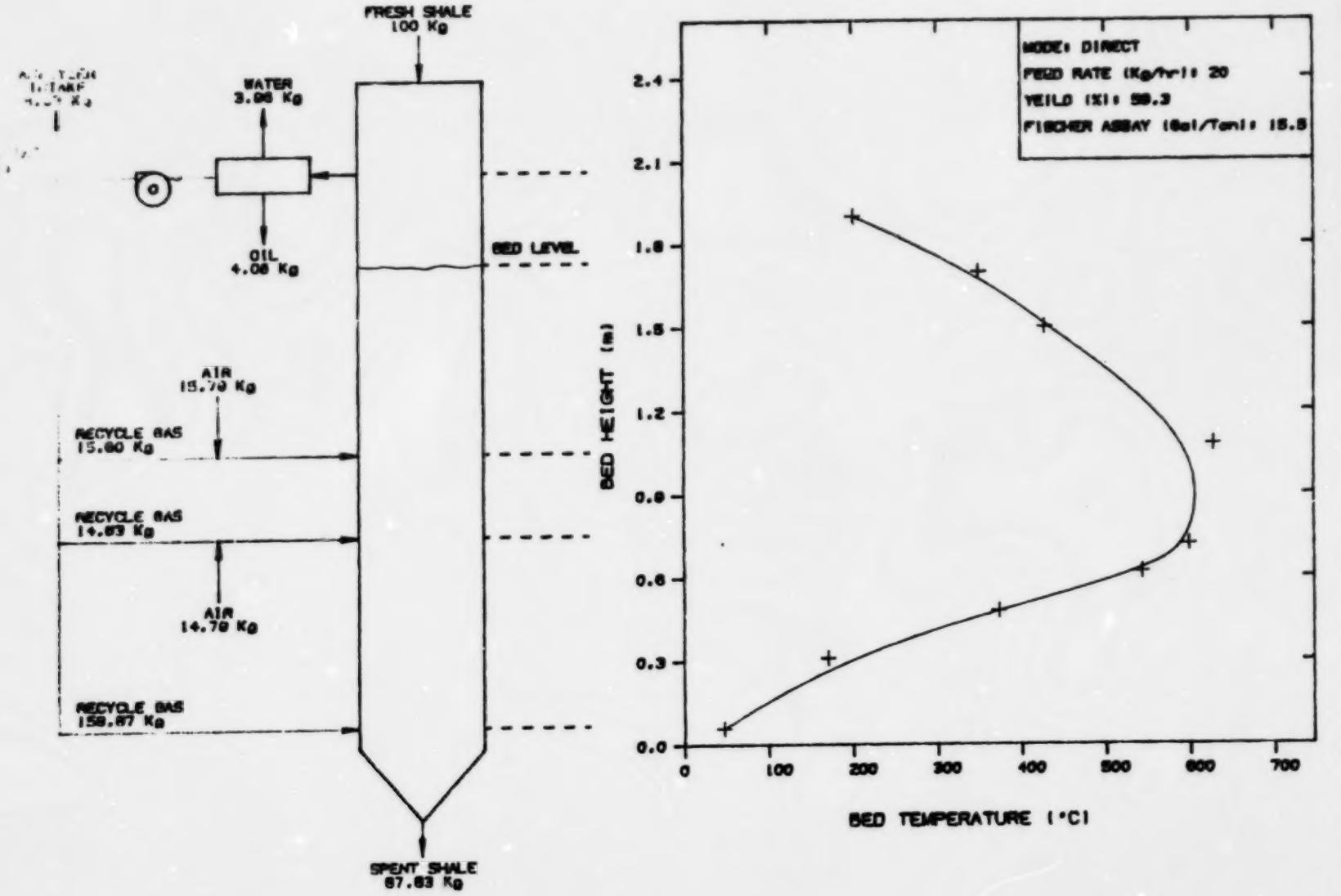


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 42

EXPERIMENT NO:42 SHALE NO: 2

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.74
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.60
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.89
RECYCLE GAS SPLIT, % : BOTTOM: 83.9 MIDDLE: 16.1

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 30.59
AIR BOTTOM: 0.
ACCUM/DEPLE: 0.
TOTAL INPUT: 130.59

OUTPUT IN KG

SPENT SHALE: 87.83
EXHAUST GAS: 25.35
ANALYZER INTAKE: 8.03
OIL PRODUCED: 4.06
WATER FORMED: 3.96
TOTAL OUTPUT: 127.23
% UNACCOUNTED: 2.57

MID AIR SPLIT
MID AIR UPPER, KG: 15.79
MID AIR LOWER, KG: 14.79

BOTTOM RECYCLE GAS, KG: 158.87
MIDDLE RECYCLE GAS, KG: 30.43

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 15.80
LOWER, KG: 14.63

GAS ANALYSIS IN MOL %

H2: 2.30
N2: 74.67
O2: 0.
CO2: 18.00
CO: 2.50
CH4: 1.38
C2: 0.72
C3: 0.280
C4: 0.150
BTU PER SCFM: 56.20

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 6.62
% OIL 35.11
% SPENT SHALE: 28.95
% GAS: 17.72

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 43.90
GAS: 12.33

YIELD, % OF F.A: 59.30

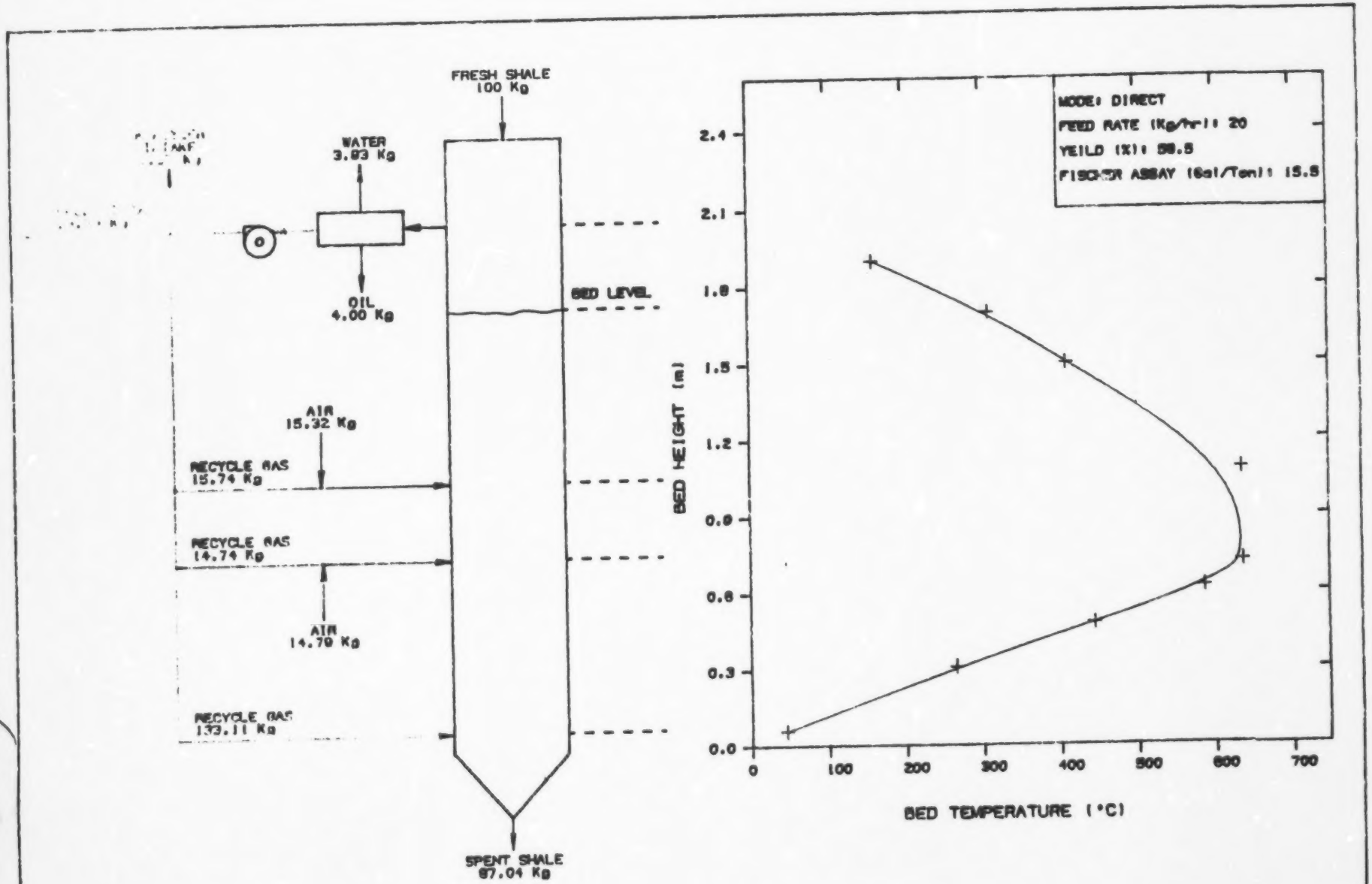


FIG 8 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 43

EXPERIMENT NO:43 SHALE NO: 2

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.74
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.60
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.64
RECYCLE GAS SPLIT, % : BOTTOM: 81.4 MIDDLE: 18.6

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 30.11
AIR BOTTOM: 0.
ACCUM/DEPLE: -1.22
TOTAL INPUT: 128.90

OUTPUT IN KG

SPENT SHALE: 87.04
EXHAUST GAS: 16.35
ANALYZER INTAKE: 7.07
OIL PRODUCED: 4.00
WATER FORMED: 3.93
TOTAL OUTPUT: 120.43
% UNACCOUNTED: 6.57

MID AIR SPLIT
MID AIR UPPER, KG: 15.32
MID AIR LOWER, KG: 14.79

BOTTOM RECYCLE GAS, KG: 133.11
MIDDLE RECYCLE GAS, KG: 30.48

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 15.74
LOWER, KG: 14.74

GAS ANALYSIS IN MOL %

H2: 2.71
N2: 74.04
O2: 0.
CO2: 17.75
CO: 2.73
CH4: 1.49
C2: 0.80
C3: 0.290
C4: 0.190
BTU PER SCFM: 62.6

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 7.46
% OIL 35.04
% SPENT SHALE: 32.06
% GAS: 14.83

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 44.08
GAS: 11.33

YIELD, % OF F.A: 58.50

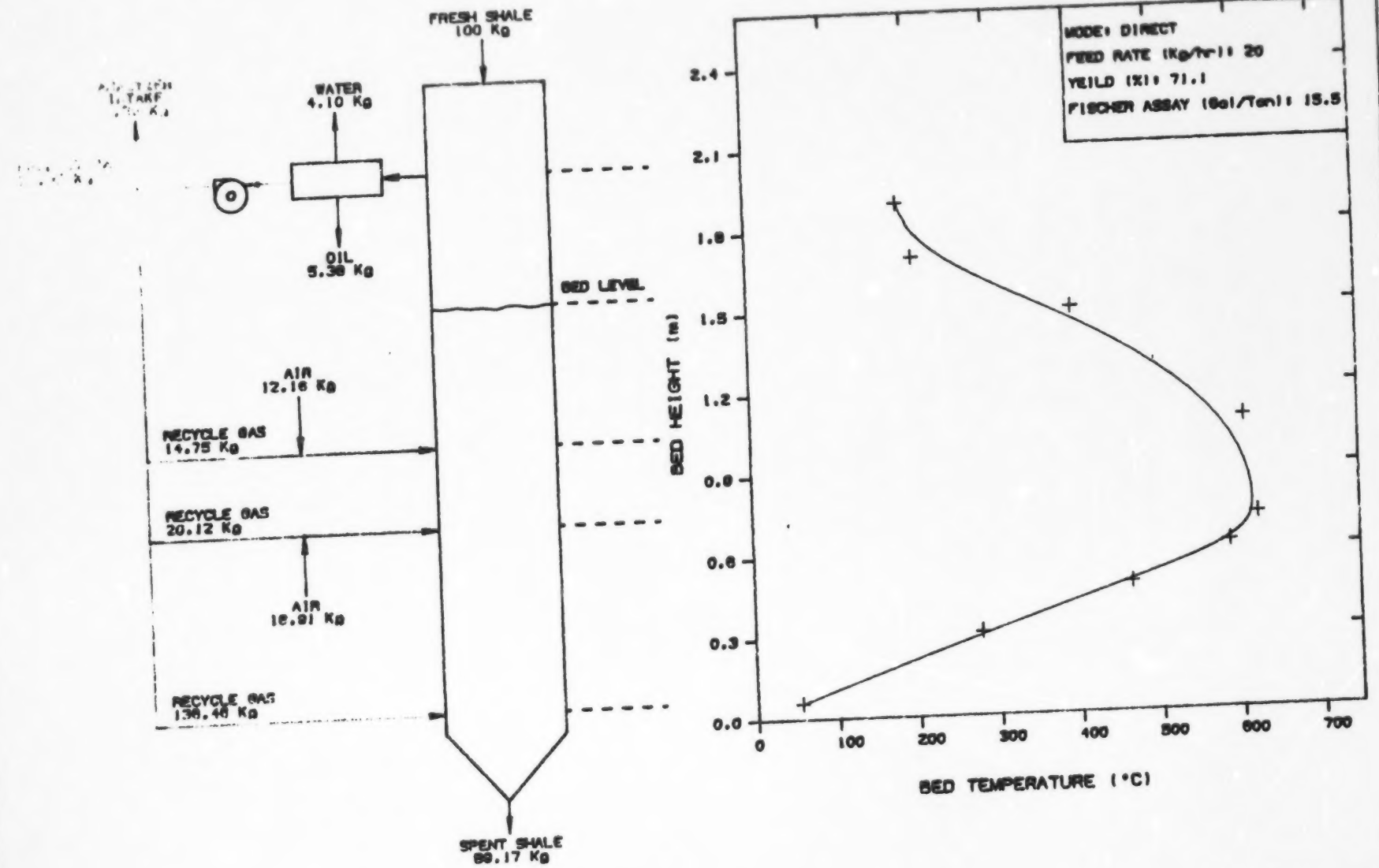


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 44

EXPERIMENT NO:44 SHALE NO: 2

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.58
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.18
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.71
RECYCLE GAS SPLIT, % : BOTTOM: 79.7 MIDDLE: 20.3

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 29.07
AIR BOTTOM: 0.
ACCUM/DEPLE: -0.61
TOTAL INPUT: 128.46

OUTPUT IN KG

SPENT SHALE: 89.17
EXHAUST GAS: 35.35
ANALYZER INTAKE: 7.39
OIL PRODUCED: 5.38
WATER FORMED: 4.10
TOTAL OUTPUT: 141.98
% UNACCOUNTED: -10.52

MID AIR SPLIT
MID AIR UPPER, KG: 12.16
MID AIR LOWER, KG: 16.91

BOTTOM RECYCLE GAS, KG: 136.46
MIDDLE RECYCLE GAS, KG: 34.87

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 14.75
LOWER, KG: 20.12

GAS ANALYSIS IN MOL %

H2: 2.81
N2: 76.56
O2: 0.51
CO2: 15.86
CO: 2.24
CH4: 1.25
C2: 0.79
C3: 0.810
C4: 0.170
BTU PER SCFM: 56.67

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 1.74
% OIL 46.74
% SPENT SHALE: 28.85
% GAS: 20.67

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 58.97
GAS: 17.45

YIELD, % OF F.A: 71.10

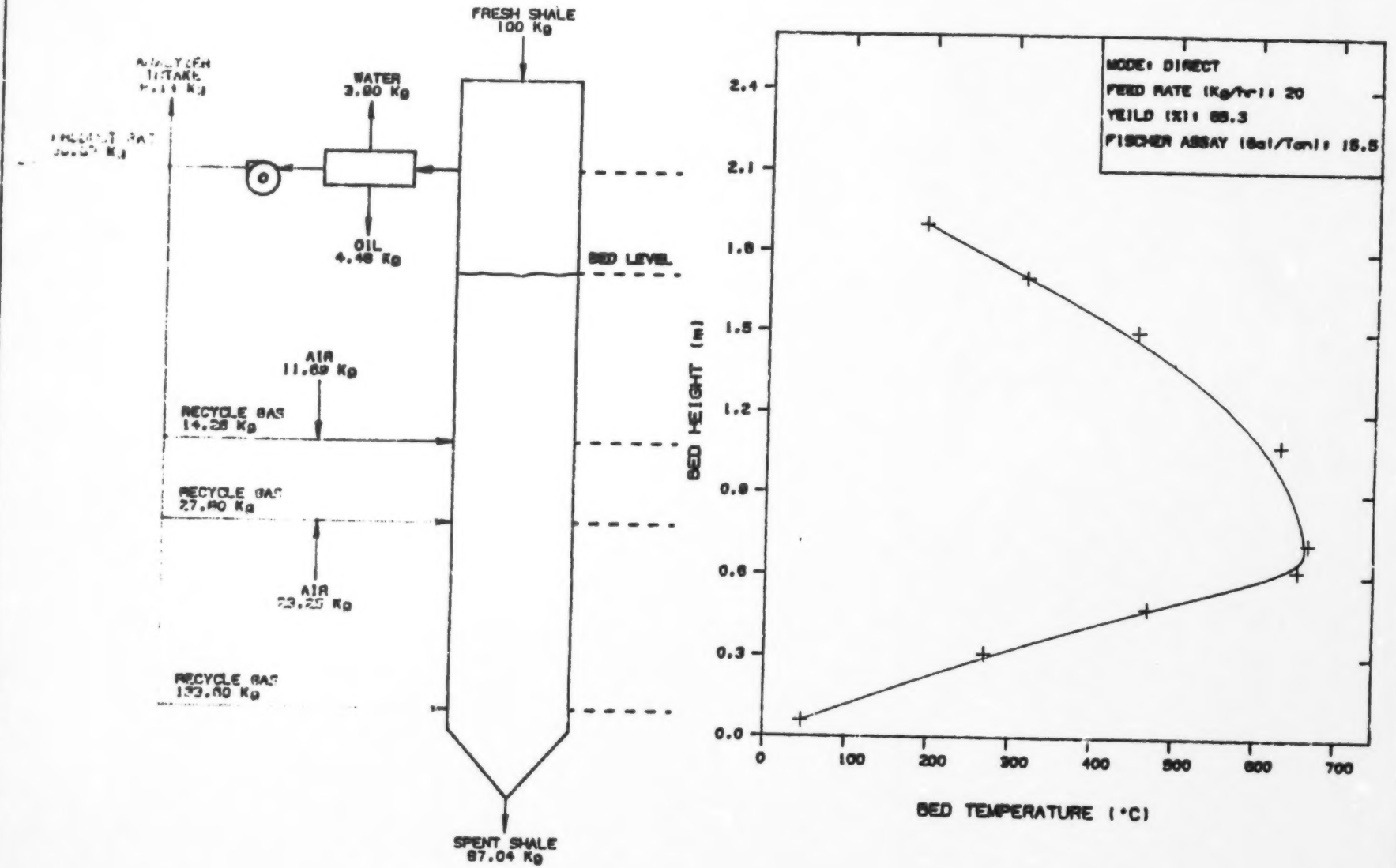


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 45

EXPERIMENT NO:45 SHALE NO: 2

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.69
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.47
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.76
RECYCLE GAS SPLIT, % : BOTTOM: 76.1 MIDDLE: 23.9

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 34.94
AIR BOTTOM: 0.
ACCUM/DEPLE: -0.51
TOTAL INPUT: 134.83

OUTPUT IN KG

SPENT SHALE: 87.04
EXHAUST GAS: 39.05
ANALYZER INTAKE: 8.14
OIL PRODUCED: 4.48
WATER FORMED: 3.90
TOTAL OUTPUT: 133.60
% UNACCOUNTED: 0.54

MID AIR SPLIT
MID AIR UPPER, KG: 11.69
MID AIR LOWER, KG: 23.25

BOTTOM RECYCLE GAS, KG: 133.60
MIDDLE RECYCLE GAS, KG: 42.06

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 14.26
LOWER, KG: 27.80

GAS ANALYSIS IN MOL %

H2: 2.61
N2: 74.04
O2: 0.
CO2: 10.72
CO: 2.49
CH4: 1.11
C2: 0.69
C3: 0.270
C4: 0.170
BTU PER SCFM: 83.92

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 4.89
% OIL 30.99
% SPENT SHALE: 29.67
% GAS: 20.37

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 49.26
GAS: 14.43

YIELD, % OF F.A: 65.80

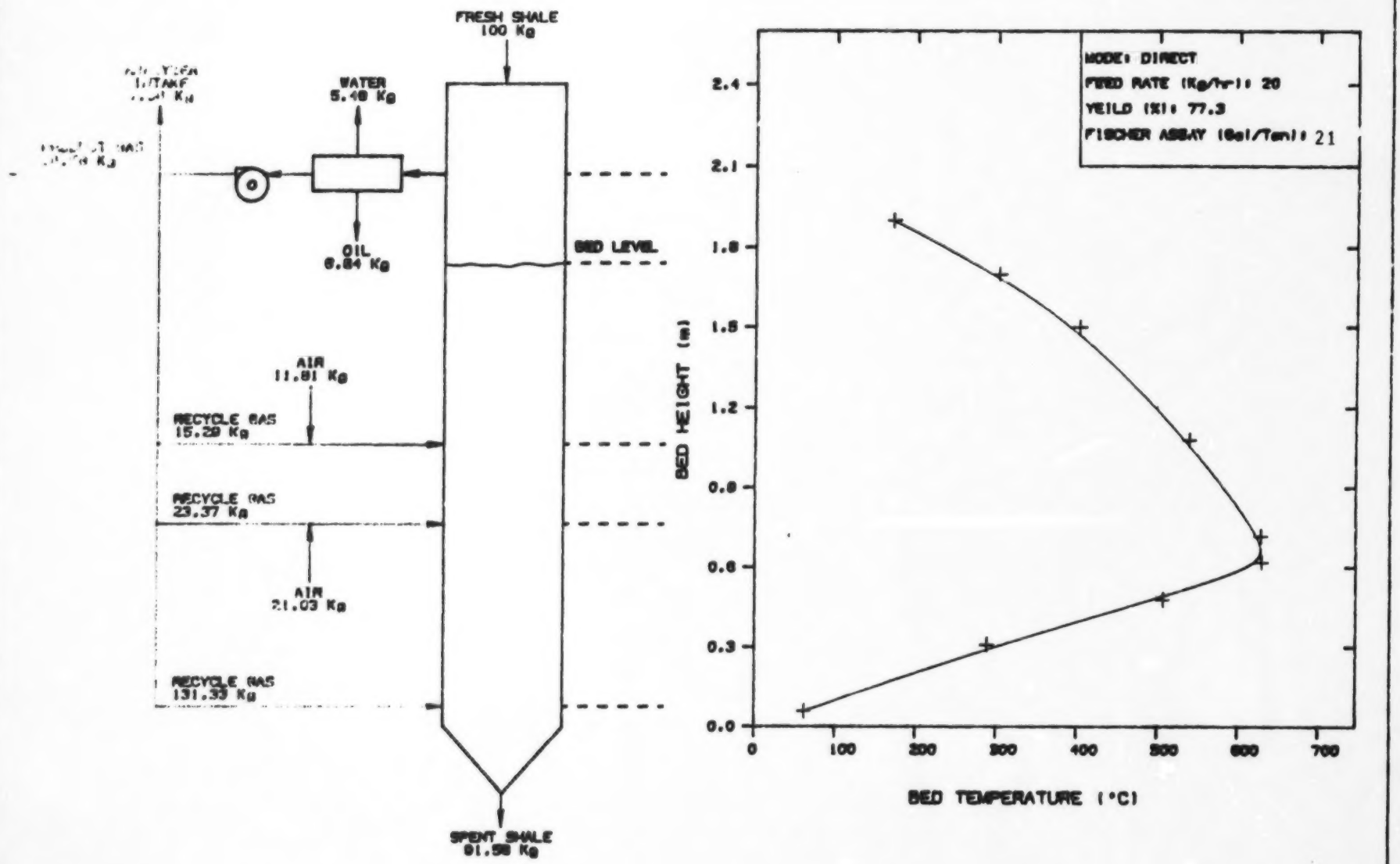


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 46

EXPERIMENT NO:46 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.74
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.60
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 1.70
RECYCLE GAS SPLIT, % : BOTTOM: 77.3 MIDDLE: 22.7

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 32.84
AIR BOTTOM: 0.
ACCUM/DEPLE: 5.48
TOTAL INPUT: 138.32

OUTPUT IN KG

SPENT SHALE: 91.58
EXHAUST GAS: 35.50
ANALYZER INTAKE: 7.06
OIL PRODUCED: 6.84
WATER FORMED: 5.48
TOTAL OUTPUT: 147.64
% UNACCOUNTED: -6.67

MID AIR SPLIT
MID AIR UPPER, KG: 11.81
MID AIR LOWER, KG: 21.03

BOTTOM RECYCLE GAS, KG: 131.33
MIDDLE RECYCLE GAS, KG: 38.66

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 15.29
LOWER, KG: 23.37

GAS ANALYSIS IN MOL %

N2: 1.92
H2: 77.88
O2: 0.51
CO2: 15.60
CO: 2.13
CH4: 0.78
C2: 0.61
C3: 0.300
C4: 0.270
BTU PER SCFM: 80.04

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: -2.17
% OIL 48.93
% SPENT SHALE: 35.04
% GAS: 15.20

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 60.07
GAS: 12.33

YIELD, % OF F.A: 77.30

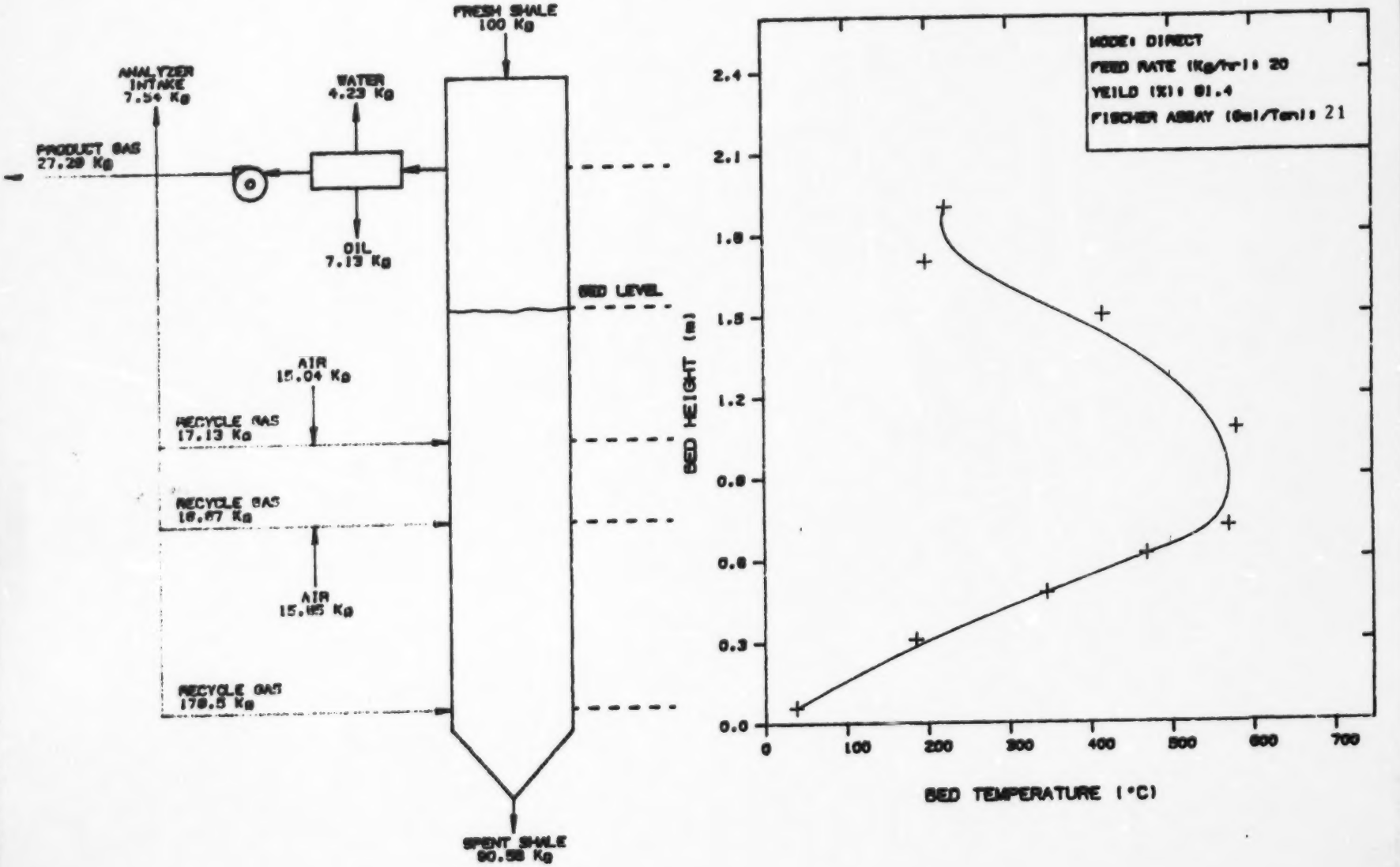


FIG 1 OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 47

EXPERIMENT NO:47 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.55
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.10
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.13
RECYCLE GAS SPLIT, % : BOTTOM: 84.2 MIDDLE: 15.8

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 30.99
AIR BOTTOM: 0.
ACCUM/DEPLE: 3.65
TOTAL INPUT: 134.64

OUTPUT IN KG

SPENT SHALE: 90.58
EXHAUST GAS: 27.29
ANALYZER INTAKE: 7.54
OIL PRODUCED: 7.13
WATER FORMED: 4.28
TOTAL OUTPUT: 136.77
% UNACCOUNTED: -1.66

MID AIR SPLIT
MID AIR UPPER, KG: 15.04
MID AIR LOWER, KG: 15.85

BOTTOM RECYCLE GAS, KG: 179.50
MIDDLE RECYCLE GAS, KG: 33.81

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 17.13
LOWER, KG: 16.67

GAS ANALYSIS IN MOL %

H2: 1.80
N2: 78.12
O2: 0.10
CO2: 15.70
CO: 2.07
CH4: 1.00
C2: 0.70
C3: 0.310
C4: 0.200
BTU PER SCFM: 51.17

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 1.28
% OIL 51.89
% SPENT SHALE: 27.62
% GAS: 13.94

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 64.39
GAS: 10.28

YIELD, % OF F.A: 81.40

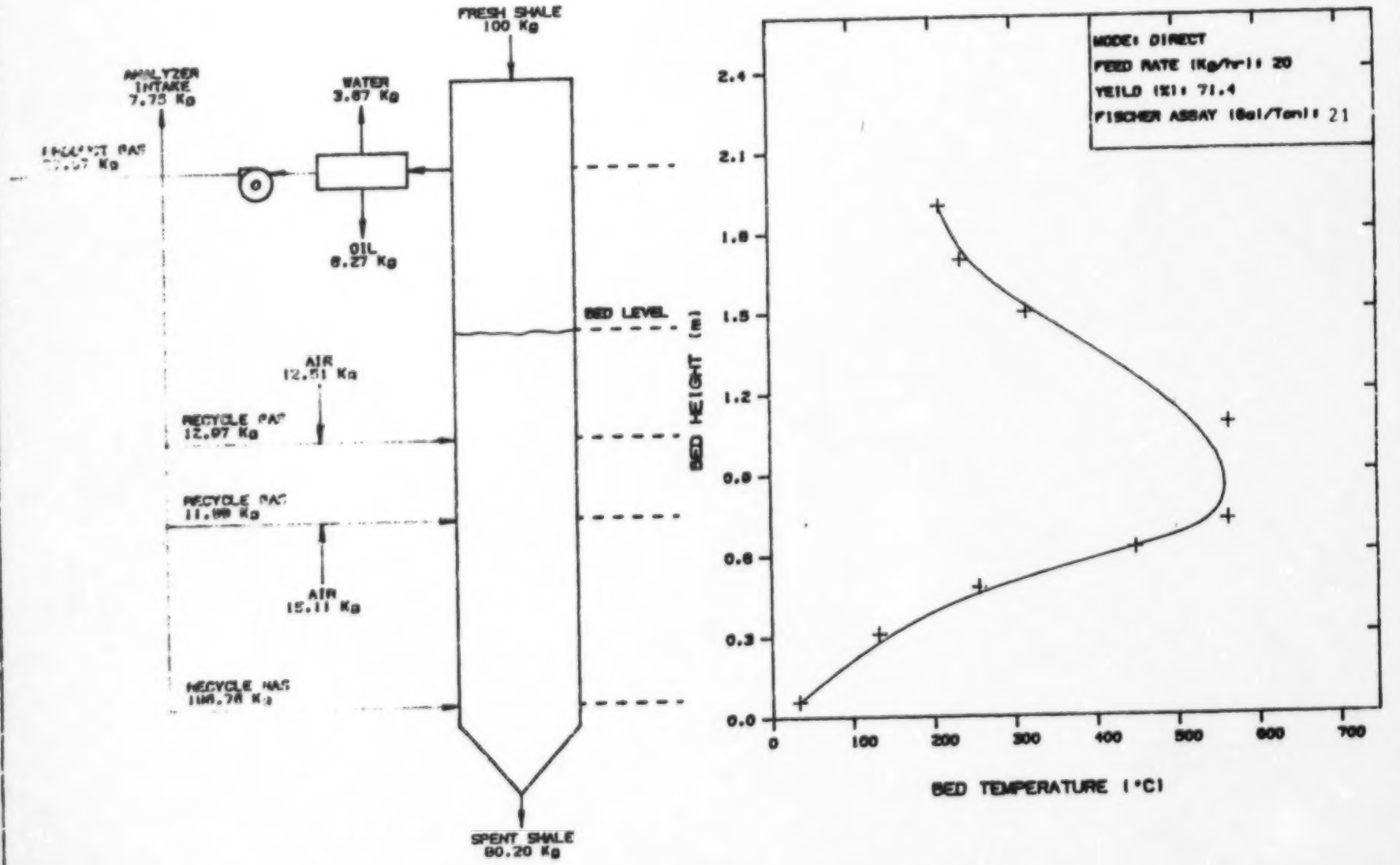


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 48

EXPERIMENT NO:40 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.46
FEED RATE, KG/HR: 20.00
DURATION, HR: 10.00
RESIDENCE TIME IN HR: 3.06
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.12
RECYCLE GAS SPLIT, % : BOTTOM: 88.3 MIDDLE: 11.7

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 27.62
AIR BOTTOM: 0.
ACCUM/DEPLE: 4.38
TOTAL INPUT: 132.00

OUTPUT IN KG

SPENT SHALE: 80.20
EXHAUST GAS: 27.01
ANALYZER INTAKE: 7.75
OIL PRODUCED: 6.27
WATER FORMED: 3.67
TOTAL OUTPUT: 124.96
% UNACCOUNTED: 5.33

MID AIR SPLIT
MID AIR UPPER, KG: 12.51
MID AIR LOWER, KG: 15.11

BOTTOM RECYCLE GAS, KG: 186.76
MIDDLE RECYCLE GAS, KG: 24.86

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 12.97
LOWER, KG: 11.88

GAS ANALYSIS IN MOL %

H2: 2.00
N2: 78.96
O2: 0.34
CO2: 14.20
CO: 1.97
CH4: 1.10
C2: 0.73
C3: 0.400
C4: 0.300
BTU PER SCFM: 88.96

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 1.19
% OIL 45.85
% SPENT SHALE: 33.36
% GAS: 14.36

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 56.28
GAS: 11.82

YIELD, % OF F.A: 71.40

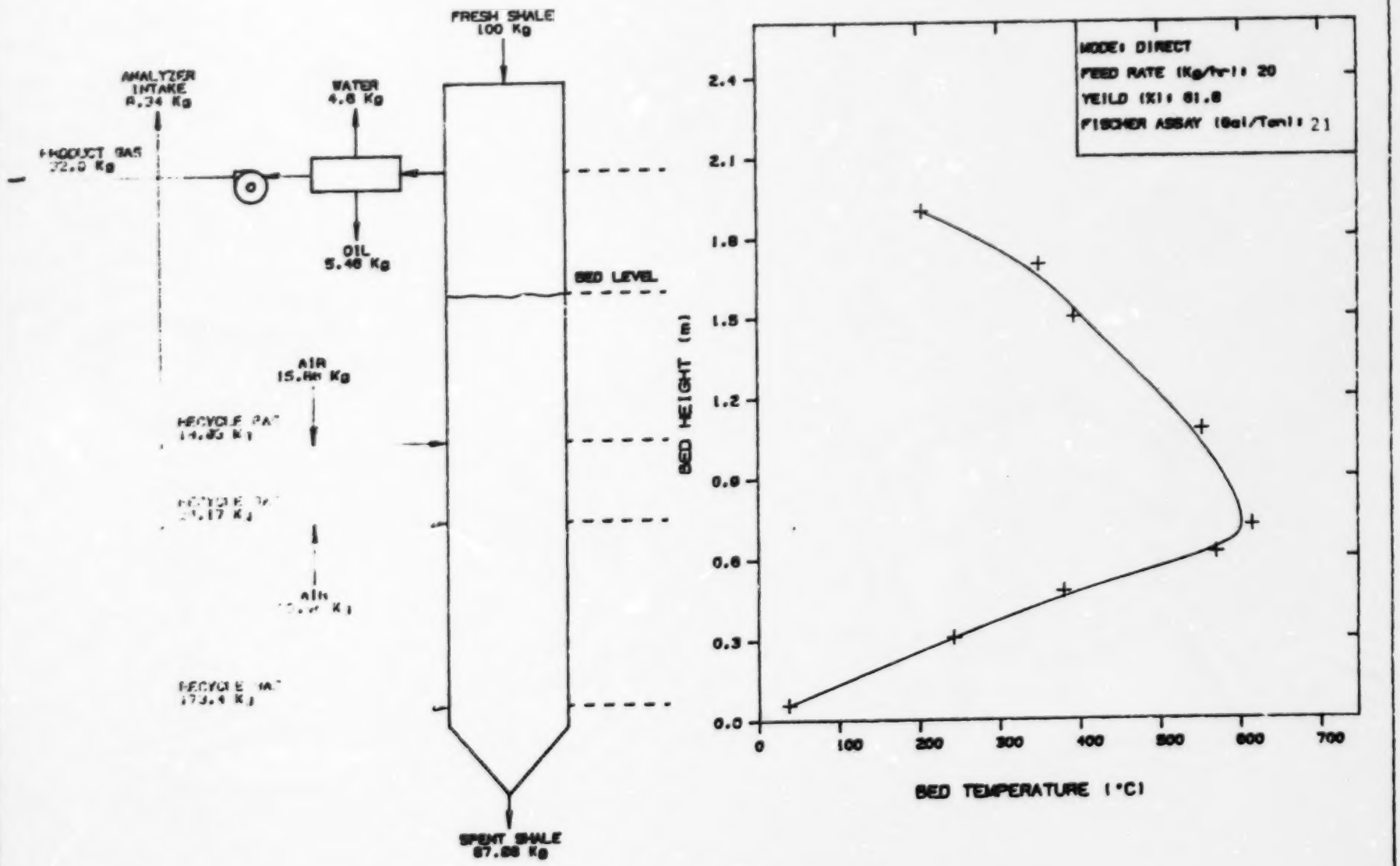


FIG : OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR RUN NO. 49

EXPERIMENT NO:49 SHALE NO: 1

MODE: DIRECT

OPERATING CONDITIONS

BED HEIGHT IN M: 1.61
FEED RATE, KG/HR: 20.00
DURATION, HR: 12.00
RESIDENCE TIME IN HR: 4.26
RATIO OF RECYCLE GAS TO SHALE, KG/KG: 2.18
RECYCLE GAS SPLIT, % : BOTTOM: 79.4 MIDDLE: 20.6

INPUT IN KG

FRESH SHALE: 100.00
AIR MIDDLE: 39.32
AIR BOTTOM: 0.
ACCUM/DEPLE: 2.43
TOTAL INPUT: 141.75

OUTPUT IN KG

SPENT SHALE: 87.96
EXHAUST GAS: 31.99
ANALYZER INTAKE: 8.34
OIL PRODUCED: 5.46
WATER FORMED: 4.60
TOTAL OUTPUT: 138.35
% UNACCOUNTED: 2.40

MID AIR SPLIT
MID AIR UPPER, KG: 15.86
MID AIR LOWER, KG: 23.46

BOTTOM RECYCLE GAS, KG: 173.39
MIDDLE RECYCLE GAS, KG: 45.11

MIDDLE RECYCLE GAS SPLIT, KG
UPPER, KG: 18.93
LOWER, KG: 26.17

GAS ANALYSIS IN MOL %

H2: 1.90
N2: 76.43
O2: 0.22
CO2: 16.40
CO: 2.40
CH4: 1.15
C2: 0.70
C3: 0.350
C4: 0.400
BTU PER SCFM: 62.23

DISTRIBUTION OF CARBON

% UNACCOUNTED CARBON: 4.39
% OIL 40.20
% SPENT SHALE: 28.02
% GAS: 17.71

ENERGY DISTRIBUTION, % OF FRESH SHALE

OIL: 50.05
GAS: 14.54

YIELD, % OF F.A: 61.80